2005

Shelf-life study of peach halves in active EVOH pouches : a color and texture analysis

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SHELF-LIFE STUDY OF PEACH HALVES IN ACTIVE EVOH POUCHES

- A COLOR AND TEXTURE ANALYSIS

A Thesis

Presented to

The Faculty of the Department of Nutrition and Food Science and

Industrial and Systems Engineering

San Jose State University

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

by

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December 2005

UMI Number: 1432477

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12/06/05

ABSTRACT

SHELF-LIFE STUDY OF PEACH HALVES IN ACTIVE EVOH POUCHES - A COLOR AND TEXTURE ANALYSIS

by Lisa Diane Gebbia

This thesis addresses a shelf-life study of canned peach halves repackaged into a flexible packaging system consisting of one-gallon EVOH pouches containing flaps of a proprietary, tin-based oxidation inhibiting material. The efficacy of this packaging system was evaluated based on changes in the color and texture of the stored peach halves. Samples were stored at 25°C to approximate ambient temperature and 35°C and 45°C to accelerate shelf-life. Browning, the shelf-life end point characteristic, was detected at 4.5 weeks in 45°C samples, at 21 weeks for 35°C samples and at 48 weeks for 25°C samples. Regression analysis on the RGB color components of the peach halves revealed that the active packaging did preserve the color of some of the samples when compared to the controls. Texture was not preserved when compared to the controls. With regard to color, the oxidation inhibiting material did extend the shelf-life of the peach halves stored in active EVOH pouches to some degree.

ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Dr. Miriam Perry, for her expertise, support, and insightful technical guidance during this research project.

I would like to thank my academic advisor and department chair, Dr. Louis Freund, for his knowledge and advice during my course of study here at San Jose State University.

I would also like to thank Professor Herbert Schueneman, Packaging Program Director, for his patient guidance and generous support throughout this research project. His knowledge and motivation greatly contributed to my pursuit of this degree.

I would like to extend my gratitude to Mr. Rob Salinas, Mr. Harry Chang and Ms. Janet Damon of Morningstar/Liberty Packing Co., Mr. Bud Tollette of H. B. Tollette and Associates, and Mr. Steve Malmquist of Tharco for providing the materials required for this research.

PREFACE

This thesis is written in publication style. The second chapter is written in the journal article format described by *Packaging Technology and Science*. The first and third chapters are written according to the guidelines outlined in the *Publication Manual of the American Psychological Association*, fifth edition, 2001.

Table of Contents

List of Figures

Chapter 3:

List of Tables

CHAPTER 1. INTRODUCTION AND REVIEW OF LITERATURE

Introduction

Typically, cultivated fresh fruit products have a short, seasonal harvesting period. During this period, the fruit is in abundant supply and is susceptible to rapid spoilage due to the activity of microorganisms or the onset of senescence due to the biochemical reactions taking place due to respiration. Preservation of the fresh fruit product after the harvest ensures the availability of high quality fruit throughout the year.

Canning is one commonly used preservation method and when processing fruit products intended for industrial use, the No. 10 can is still widely used. These cans, however, are costly, heavy, and space consuming. According to Harry Chang, the Production Manager at the Liberty Packing Company (Los Banos, CA), a No.10 can costs approximately 50 cents per unit. When these large, round cans are palletized or packed into square corrugated containers for shipping, spatial gaps remain between the cans resulting in an inefficient use of the shipping container. Flexible packages offer a less expensive, more space efficient method for shipping, storing, and presenting many food products. In addition, trends in the marketplace as witnessed by consumer demands for transparency, convenience (easy opening and re-closing functions), fresher products, and the avoidance of aluminum and chlorine in packaging materials, all translate into higher demand for flexible packages.

Based on these reasons The Morningstar Company, in conjunction with The Liberty Packing Company, has been investigating a replacement for the No. 10 can to package fresh peach products. Such a replacement is already being successfully utilized for their tomato products. Known as the "bag-in-box," tomato products are processed and stored in 200 gallon aseptic bags supported by plastic, steel, or fiber drums. Once packaged, the products can maintain a shelf-life of several years even under temperature conditions in excess of 95°F.

Significance of Study

In a preliminary study done by Morningstar, an attempt was made to package peach products using the same bag-in-box technology that is used for their tomato products. Peaches were packed into a 200 gallon aseptic bag, boxed, and then stored under uncontrolled atmospheric conditions at the Los Banos packing plant. Upon inspection two months later, the peaches closest to the outer sealed edges of the bag had browned. Since brown color is an unacceptable condition for peach products, the packaging system was deemed unsuccessful for peaches.

In order to test a new oxidation inhibiting material thought to prevent peaches from browning while stored in flexible bags, an agreement was made between H. B. Tollette & Associates (Sacramento, CA), The Morningstar Company (Los Banos, CA), and San Jose State University (San Jose, CA) to conduct a more controlled and more extensive shelf-life study under the auspices of the university with materials and resources donated by H. B. Tollette & Associates, The Morningstar Company, and Westpak, Inc (San Jose, CA).

Morningstar originally wanted 200 gallon pouches to be used in the study. Since quantities of this size were not feasible for a university study, the use of one-gallon flexible pouches as a basis for the study and to establish a proof of concept for the new packaging system was agreed upon. Morningstar required a real-time, ambient condition (25°C assumed to be ambient), two-year shelf-life study. The first year of this study was conducted by one research team. The second year of the study was to be completed by a second research team. A six-month study at 45°C and a twelve-month study at 35°C were added to the initial study for comparison with regard to temperature conditions. This accelerated shelf-life study was conducted for two reasons: 1) to get an idea of the relative efficacy of packaging with the oxidation inhibitor on peach quality and 2) to get an idea of the relative temperature sensitivity of quality changes in peaches.

Objective

The objective of this study was to assess the efficacy of EVOH pouches containing several different amounts of oxidation inhibiting material on the color and texture qualities of the peach halves with regard to temperature. The peaches were studied at temperatures of 25, 35, and 45°C in order to determine if the pouch, in conjunction with the proprietary oxidation inhibiting material, prolonged the shelf-life of the peaches with regard to color and texture. To achieve this objective, an accelerated shelf-life test was employed.

Review of Literature

Canned Peaches

Canned Peach Processing

Several major operations are required to produce canned peach products. Based on observations during a visit to the Liberty Packing Plant in Los Banos, CA in July 2004, the process flow required to produce canned peach halves can be summarized as follows: the whole, fresh fruit was loaded from a bin into a hopper and fed onto an aqueous conveyor. Here, much of the peach fuzz and debris (twigs, stems, and leaves) was washed away. The fruit was then halved and pitted. The pits were discarded and any damaged halves or undersized peach pieces were separated out for slicing or dicing. The peach halves were then immersed in a hot caustic lye bath for approximately 30 seconds. The loosened skin and residual lye was removed with water jets. The peeled peaches were then blanched for approximately one minute to remove any final traces of lye and to inactivate the oxidase enzyme that causes the exposed surfaces of the fruit to brown when in contact with air. The fruit was then filled into cans where juice or syrup (light or heavy) was added. The cans were then sealed, pasteurized with steam and quickly cooled with several cold water baths. The cans were then sent via conveyor to the packing area where they were palletized and shipped out for labeling, repackaging, and sale.

Canned Peach Quality

There are numerous federal and state regulations which govern the processes used for canning peaches. Two of the most applicable federal regulations are the Food and Drug Administration's (FDA) Code of Federal Regulations (CFR) Title 21 Part 110 – Current Good Manufacturing Processes (GMPs) for Manufacturing, Packing or Holding Human Food and CFR Title 21 Part 145.170 - Canned Peaches. One state regulation which applies to canned peaches is the California Code of Regulations (CCR) Title 17 – Heat Processed Canned Peaches. In addition, there are industry standards which dictate strict quality guidelines used by processors throughout the industry. The Morningstar Company/The California Fruit Packing Company provided documentation which describes the grading process used for their canned Clingstone peach halves. The factors used are color, size, symmetry, defects and character where the character of the peach is its texture. Of these factors, color, size, and texture are the key factors used to assess peach quality. Prior to pasteurization, sample cans are manually assessed by quality assurance personnel according to these quality standards.

Packaging Methods

Canning

Food canning really began in 1809 when Nicolas Appert first discovered that if food was sufficiently heated in a sealed container and the container remained sealed, the food would be preserved. This discovery eventually evolved into modern canning methods. The original "tin cans" were actually steel cans coated with a thin electrolytically deposited coating of tin to prohibit corrosion of the can by the food. More recently, due to the expense of tin, cans in the U.S. have been made of various grades of corrosion-resistant steel alloys (Potter & Hotchkiss, 1995). The grade used for mildly acidic fruit products such as peaches is known as Type MR - medium residual. This refers to the amount of residual metal elements other than phosphorous and is the most common can-making steel (Soroka, 2002).

Modified Atmosphere Packaging

The objective of Modified Atmosphere Packaging (MAP) is to extend the shelf-life and maintain the quality of fresh food products by reducing the respiration rate of the packaged product (Jacobsson et al., 2004). In MAP, air is replaced by a mixture of gases usually comprised of different concentrations of nitrogen, carbon dioxide and reduced levels of oxygen. Nitrogen is used as a relatively impermeable inert filler and carbon dioxide is known to suppress the growth of bacteria and molds (Miltz & Perry, 2005). The displacement of oxygen by nitrogen and carbon dioxide in the package reduces deteriorative oxidation reactions. Advantages of MAP for food products include increased shelf-life and quality and decreased need for chemical preservatives and decreased waste due to spoilage (Parry, 1993).

Recently, MAP has begun to replace the use of cans in many areas of food packaging, especially that of fresh produce. The costly, opaque, heavy, and space consuming can has yielded to the less expensive, transparent and more convenient flexible pouch. Consumer demand for fresh, minimally processed, ready-to-use produce has fueled this trend.

Designing MAP for fresh produce is a complicated task since many factors such as film characteristics (O_2 and CO_2 permeability, thickness, surface area, etc.), temperature, headspace inside the package, product weight, and respiration parameters must all be taken into account. Passive MAP for a particular product requires careful selection of a film to obtain an optimal O_2 and CO_2 atmosphere inside the package (Charles et al., 2003).

Mathematical models can be used to define the package requirements for MAP and several models are available (Edmond et al., 1991; Fishman et al., 1995). These models use the principles of O_2 and CO_2 mass balances to describe interactions among the product respiration, film permeability, and the environment. In many cases it takes a long time to reach O_2 and CO_2 gas equilibrium. Cameron et al. 1995 showed that it can take two to three weeks to attain a steady-state condition at low temperatures depending on the void volume and rate of product respiration. During this time the product is exposed to unsuitable gas composition and prohibited from benefiting from the positive effects of the steady-state atmosphere.

The use of passive MAP for fresh produce is restricted mainly by the unavailability of appropriate films that provide gas permeability, selectivity, and temperature compensation to function effectively (Exama et al., 1993). There is only a limited ability to regulate a passively established modified atmosphere within a hermetically sealed package (Day, 1994). For many foods, the levels of residual oxygen that can be achieved through regular MAP technologies are too high for maintaining the desired quality and for achieving the maximum shelf-life (Miltz & Perry, 2005).

With respiring fresh produce, it would be advantageous to have film permeability increase with temperature (at least as much as the respiration rate increases) to avoid anaerobic conditions and to retain the shelf-life of the product. The permeation rates of most food packaging films do not change with regard to temperature. Recently, however, the Landec Company (Menlo Park, CA) has developed a dynamic film with a "temperature-switch" point. When the temperature reaches this predetermined point, the film's permeation rates change rapidly and dramatically. Landec's technology uses long-chain fatty alcohol-based polymeric chains. At temperatures below the predetermined switch point, these chains are in a crystalline state, providing a gas barrier. At the specified temperature-switch, the side chains melt to provide a gas-permeable amorphous state (Alzamora, 2000). Actively establishing the atmosphere in a package is now possible and rapidly becoming a method of choice for fresh and minimally processed fruit and vegetable products.

Active MAP

Active MAP consists essentially of gas flushing or gas scavenging (O_2, CO_2, ethylene etc.) to quickly establish an equilibrium condition within a package to avoid high levels of undesirable gases (Charles et al., 2003). Oxygen absorbers are used to rapidly decrease the O_2 partial pressure from package headspace and also to remove the O_2 that permeates through the packaging film (Rooney, 1995). To date, oxygen absorbers have been successfully used with non-respiring products such as meat and pastries (Brody et al., 2001).

For respiring produce, such as fresh fruits and vegetables, more research is needed to investigate the use of gas absorbers inside a package to determine how they can be used to maintain the desired package atmosphere. One problem with reduced O_2 in MAP of fresh or minimally processed produce is that if the oxygen level in the package is under the produce tolerance limit, it may lead to anaerobic conditions. Such conditions may result in the production of malodorous compounds and the growth of pathogenic anaerobic microorganisms such as Clostridium botulinum (Charles et al., 2003).

Many product-package interactions can result in a negative effect on the product, package, or both. In active packaging, the product, the package, and the environment interact in a positive way, resulting in an extension of the product's shelf-life (Miltz & Perry, 2005). Active packaging is intended to sense internal or external environmental change and to respond by changing its own properties and hence that of the internal package environment (Brody, et al., 2001).

Oxygen Scavengers

"Oxygen scavenger is a term used to describe materials incorporated into a package structure that chemically combines with, and thus effectively removes, oxygen from the inner package environment. Scavengers are fast-acting, high-capacity oxygen interceptors capable of eliminating relatively large volumes of oxygen and continuing their action indefinitely as long as the scavenger is present" (Brody, et al., 2001). Commercial oxygen scavengers are made of easily oxidizable substances, usually finely ground iron powder (Andersson, et al., 2002).

Some of the many adverse effects of oxygen on and in foods and beverages are described in *Active Packaging for Food Applications.* These effects are:

(1) Oxidative rancidity of unsaturated fats leading to off-flavors and even, in extreme circumstances, to toxic end-products
(2) Loss of ascorbic acid or vitamin C, especially in fruit and vegetable based foods
(3) Darkening and browning of fresh meat pigments
(4) Fostering growth of aerobic spoilage microorganisms
(5) Staling odors in soft bakery goods
(6) Hatching of insects eggs and growth of insects
(7) Acceleration of fresh fruit and vegetable respiration
(8) Enzymatic and nonenzymatic phenolic browning of fresh fruit flesh
(9) Oxidation of aromatic flavor oils of beverages such as coffee and tea
(10) Flavor deterioration of beer
(11) Discoloration of processed fruit and vegetable pigments

(Brody, et al., 2001)

These adverse effects can be reduced or eliminated by controlling the amount of oxygen in a packaging system. To optimize the effects of oxygen scavenging, oxygen should first be removed from the product during processing and packaging operations. Reducing or eliminating the oxygen from the package environment can be accomplished by a wide variety of mechanical means during the formation and closure of the package. However, this is only a one-time activity. Even when as much oxygen as possible is initially removed from the package, trace amounts of oxygen still remain in the headspace or dissolved in the product. Even these low concentrations can be enough to promote the detrimental biochemical processes that degrade quality. In addition, oxygen from the air can enter a package by permeation through plastic films, seam compounds, or by transmission through heat-seal faults, pinholes, or cracks (Brody, et al., 2001, Andersson et al., 2002).

Oxygen scavengers are a part of active packaging because they perform an ongoing function during the storage life of the packaged product (Foltynowicz et al., 2002). In addition to the extension in shelf-life, oxygen scavengers have been shown to improve the quality of the product during the storage period (Labuza & Breene, 1989). Another advantage is a reduction in the amount of preservatives that are needed to ensure the quality of the food product throughout the storage period (Andersson, et al., 2002).

Forms of Oxygen Scavengers

Sachets

The most significant oxygen scavengers in commercial use today are based on ferrous iron. Due to the toxicity of this compound, it must not be consumed or allowed to come into direct contact with food products. To prevent contamination, the powder is contained in small gas-permeable sachets. These sachets can be found suspended under the lids of containers or in among the food product. As required by the FDA, these must be labeled "Do not eat." The US Department of Agriculture (USDA) has approved their use in indirect contact for packaging beef jerky, dehydrated meat, and poultry products (Brody et al., 2001).

Although quite effective for certain applications, sachets are not appropriate for inclusion in packages containing liquid products or in packages where the packaging material clings to the food, isolating the sachet from areas of oxygen entrapment or ingress (Andersson, et al., 2002). If placed under the lid of a container, their activity is limited to the oxygen in the headspace of the container (Miller et al., 2003). Another limitation is their dependence on the water activity in the food for activation which restricts their use to moist products. In addition, they have the ability to trigger metal detectors on packaging lines (Brody, et al., 2001). In order to expand the application of oxygen scavengers to other types of packaged food products, researchers began looking at ways to incorporate the oxygen scavenger into the packaging structure itself.

Multi-layer Films

One alternative to the sachet is a flat, flexible flap, or label where the iron is spread out over the surface area of the film. The iron is entrapped preventing it from interacting with the food. These pressure-sensitive labels can be affixed to the interior of processed meat packages to prevent browning of the product during storage. Another alternative is to incorporate scavenger compounds into roll or sheet stock used for thermoformed trays, tubs and cups, or as extruded or injection blow-molded bottles. A typical film of this variety has three layers. The outer layer has low-oxygen permeability (1 to 10cc O_2/m^2/day at 25°C), the middle layer is the oxygen scavenging layer, and the inner layer has a high gas permeability to allow the oxygen in the package access to the oxygen-scavenging layer (Brody et al., 2001).

In 1977 Scholle (Chicago, IL) introduced a multi-wall flexible pouch material containing a sulfite compound to react with oxygen. Here, the sulfite was incorporated into the package in liquid form and trapped between two layers of flexible polymeric film. The exterior ply had low oxygen permeability and the liquid core was intended to react with any oxygen entering the package from the outside environment, thus preventing it from entering the package interior. The package was intended for use with liquids such as wine, tomato paste, and tomato ketchup (Brody et al., 2001). Today, the Scholle Bag-in-box has revolutionized the wine industry where it has increasingly replaced the traditional bottle and cork. It is also seen in the soft drink industry as a delivery system for fountain syrup; in the dairy industry where it is the standard container for bulk milk for dispensers; and in the food industry where tomatoes, bananas, pineapple, and other processed fruits and vegetables are aseptically packed in bags in either drums or totes (www.scholle.com).

In 1998 Cryovac (Duncan, SC) introduced a light-activated polymeric oxygen scavenging film called OS1000. Where other oxygen-scavenging systems require excessive heat and/or moisture for activation, this film is light-activated and can remain in a non-scavenging state until triggered by UV radiation. This trigger step is easily incorporated into the packaging process and allows for no special handling during distribution and storage of the film stock. When used as a headspace scavenger, it is capable of taking oxygen levels in modified atmosphere packages to less than 0.1% in 3 – 10 days. When used on shelf-stable processed tomato products packed in flexible pouches, the rate of color degradation was reduced by 50% over 18 months (Brody et al., 2001). This oxygen scavenging technology is based on a reaction designed to remove oxygen without producing malodorous end compounds and is used today to package fresh, dried, cured and cooked meat, baked goods, fresh pasta, snack foods, nuts, and coffee (www.cryovac.com).

Ethylene Vinyl Alcohol Films

Ethylene vinyl alcohol (EVOH), a high oxygen barrier resin, was first applied to food packaging in 1984 (Morris, 2003). *Fundamentals of Packaging Technology* defines EVOH as:

> A copolymer of polyethylene in which varying amounts of the –OH functional group have been incorporated. EVOH is one of the best oxygen barriers available to packagers. However, its susceptibility to water requires that for most applications it be laminated into a protective sandwich with materials that will keep the EVOH layer away from water. (Soroka, 2002)

In general, the barrier performance of a particular polymeric material is determined by both intrinsic and extrinsic factors. Intrinsic factors are related to the crystallinity, orientation, chain stiffness, free volume, and cohesive energy density of the polymer, whereas extrinsic factors include temperature and moisture conditions to which the polymer is exposed (Zhang, et al., 2001). Water vapor and oxygen permeability are two of the most important barrier properties of a polymer used for food packaging. With its very low oxygen permeability rate, EVOH is utilized mainly for its oxygen barrier capabilities. A comparison of the barrier properties of some commonly used packaging materials is shown in Table 1.

Table 1. Typical film barrier properties of some commonly used packaging materials.

Material	**Water Vapor Permeability** g/100 in^2/day @ 90% RH	**Oxygen Permeability** cc/0.001 in/100 in^2/day
Ethylene-vinyl alcohol (EVOH)	Absorbs water	0.02
Polyamide (Nylon)	25	3
Polypropylene (PP)	0.4	150
High Density Polyethylene (HDPE)	0.3	110
Low Density Polyethylene (LDPE)	1.2	450

(Soroka, 2002)

Such limited oxygen permeation through EVOH is attributed to high intermolecular and intramolecular cohesive energy of the polymers. However, they are very sensitive to moisture and lose much of their barrier properties at high relative humidity (RH). It is believed that water molecules absorbed by EVOH at high RH interact with hydroxyl groups in the polymer matrix and weaken the existing hydrogen bonds between polymer molecules. As a result, the motion among the segments of the chain is enhanced, thereby changing its transport and mechanical properties (Zhang et al., 2001). Although increasing RH does not usually affect the barrier properties of most polymers, the oxygen barrier properties of EVOH are dramatically affected. They drop by nearly two orders of magnitude when going from dry to very high water activities (Lagaron et al., 2003).

A barrier function can be incorporated into a polymeric packaging material in one of two ways; either the barrier material can be incorporated as a layer in a multi-layer structure or it can be blended directly into the base polymer. Blending uses smaller amounts of the barrier polymer and it is a less complicated and less costly technology than co-extrusion or co-injection. Several large suppliers have recently introduced or are currently developing new barrier technologies. DuPont (Wilmington, DE) has a blend of EVOH in PE under development which has been found to be less sensitive to humidity than a typical EVOH laminate (Lange & Wyser, 2003).

CHAPTER 2. JOURNAL ARTICLE

Author's Title Page

SHELF-LIFE STUDY OF PEACH HALVES IN ACTIVE EVOH POUCHES

- A COLOR AND TEXTURE ANALYSIS

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ABSTRACT

This study was initiated to determine the efficacy of a flexible, active packaging system on peach halves. The packaging system consisted of one-gallon EVOH pouches containing flaps of a proprietary, tin-based oxidation inhibiting material. Pouches with no oxidation inhibiting material and canned peach halves served as the controls. The efficacy of this packaging system was evaluated based on changes in the color and texture of the stored peach halves. Samples were stored at 25°C to approximate ambient temperature and 35°C and 45°C to accelerate shelf-life. Browning, the shelf-life end point characteristic, was detected at 4.5 weeks in 45°C samples, at 21 weeks for 35°C samples and at 48 weeks for 25°C samples.

Regression analysis on the RGB color components of the peach halves revealed that the active packaging did preserve the color of some of the samples when compared to the control. Texture was not preserved when compared to the control. With regard to color, higher levels of the oxidation inhibiting material did extend the shelf-life of the peach halves stored in active EVOH pouches to some degree.

Keywords: oxidation, active packaging, EVOH

INTRODUCTION

Typically, cultivated fresh fruit products have a short, seasonal harvesting period. During this period, the fruit is in abundant supply and is susceptible to rapid spoilage due to the activity of microorganisms or the onset of senescence due to the biochemical reactions taking place due to respiration. Preservation of the fresh fruit product after the harvest ensures the availability of high quality fruit throughout the year.

Canning is one commonly used preservation method and when processing fruit products intended for industrial use, the No. 10 can is still widely used. These cans, however, are costly, heavy, and space consuming. Flexible packages offer a less expensive, more space efficient method for shipping, storing, and presenting these food products. In addition, trends in the marketplace as witnessed by consumer demands for transparency, convenience (easy opening and re-closing functions), fresher products, and the avoidance of aluminum and chlorine in packaging materials, all translate into higher demand for flexible packages.

The objective of Modified Atmosphere Packaging (MAP) is to extend the shelf-life and maintain the quality of fresh food products by reducing the respiration rate of the packaged product.[1] In MAP, air is replaced by a mixture of gases usually comprised of different concentrations of nitrogen, carbon dioxide, and reduced levels of oxygen. Nitrogen is used as a relatively impermeable inert filler and carbon dioxide is known to suppress the growth of bacteria and molds.[2] The displacement of oxygen by nitrogen and carbon dioxide in the package reduces deteriorative oxidation reactions. Advantages of MAP for food products include increased shelf-life and quality and decreased need for chemical preservatives and decreased waste due to spoilage.[3]

Active MAP consists essentially of gas flushing or gas scavenging (O_2, CO_2, ethylene etc.) to quickly establish an equilibrium condition within a package to avoid high levels of undesirable gases.[4] Oxygen absorbers are used to rapidly decrease the O_2 partial pressure from package headspace and also to remove the O_2 that permeates through the packaging film.[5] To date, oxygen absorbers have been successfully used with non-respiring products such as meat and pastries.[6]

For respiring produce, such as fresh fruits and vegetables, more research is needed to investigate the use of gas absorbers inside a package to determine how they can be used to maintain the desired package atmosphere. One problem with reduced O_2 in MAP of fresh or minimally processed produce is that if the oxygen level in the package is under the produce tolerance limit, it may lead to anaerobic conditions. Such conditions may result in the production of malodorous compounds and the growth of pathogenic anaerobic microorganisms such as Clostridium botulinum.[7]

Many product-package interactions can result in a negative effect on the product, package, or both. In active packaging, the product, the package and the environment interact in a positive way, resulting in an extension of the product's shelf-life.[8] Active packaging is intended to sense internal or external environmental change and to respond by changing its own properties and hence that of the internal package environment.[9]

Oxygen scavengers are a part of active packaging because they perform an ongoing function during the storage life of the packaged product.[10] In addition to the extension in shelf-life, oxygen scavengers have been shown to improve the quality of the product during the storage period.[11] Another advantage is a reduction in the amount of preservatives that are needed to ensure the quality of the food product throughout the storage period.[12]

Therefore, the objective of this study was to assess the efficacy of ethylene vinyl alcohol (EVOH) film pouches containing several different amounts of oxidation inhibiting material on the color and texture qualities of stored peach halves. The peaches were studied at temperatures of 25, 35, and 45°C in order to determine if the pouch, in conjunction with the proprietary oxidation inhibiting material, prolonged the shelf-life of the peaches with regard to color and texture. To achieve this objective, an accelerated shelf-life test protocol was employed.

MATERIALS AND METHODS

Materials

The canned peaches were donated by Liberty Packing Company (Los Banos, CA) in No. 10 cans. The peaches were from fresh 2004 season stock and packed in light syrup (14 – 18°B) with 30-35 halves per can. The proprietary oxidation inhibiting material and EVOH pouches were donated by H. B. Tollette & Associates (Sacramento, CA). The oxidation inhibiting material was composed of a polyethylene film with a tin-based compound printed onto one side of the sheet. The EVOH pouches were manufactured by Shannon Packaging (Chino, CA) and were a coextruded Nylon/EVOH/Poly film approved for food contact applications by the Food and Drug

Administration (FDA). The manufacturer states that they were a "seven layer film with excellent barrier and oxygen transmission rate properties." The technical data provided by the manufacturer for these pouches is provided in Table 1.

Table 1. Technical Data for EVOH pouches used in shelf-life study

Property	**Unit**	**ASTM Method**	**Value**
Standard Thickness	Micron	D-2103	3.0
Yield	in^2/lb	FPA B-11	9133
Oxygen Transmission	$cc/100\ in^2/day$	D-398 (@100°F/90%RH)	0.02
Water Vapor Transmission	$g/100\ in^2/day$	F-1249 (@73°F/0%RH)	0.26

Methods

A manual hot fill process took place in the pilot plant for the Nutrition and Food Science Department at San Jose State University in August of 2004. Two researchers manually performed all tasks required for this process which took four days to complete. Cans were taken from the pallet and opened in batches of three. The contents of the cans were poured into a three gallon kettle. The peaches and their syrup were then heated to a temperature of 195°F and held at that temperature for three minutes. The pouches were then filled, sealed, cooled in an ice water bath, dried, labeled, and placed into shipping containers. A Sentinel thermal sealer was used for heat sealing the EVOH pouches with settings of 3.5 sec, 350°F and 62psi. The stock shipping containers were donated by Tharco (San Lorenzo, CA). The samples were then transported to Westpak, Inc. (San

Jose, CA) where they were sorted and placed into temperature controlled storage. All color and texture evaluations took place at Westpak, Inc.

EXPERIMENTAL DESIGN

The independent variable in this study was the oxidation inhibiting material and its effect on the peaches. Four different levels of the oxidation inhibiting material were used in the EVOH pouches; one 4"x 4" square (T1), two 4"x 4" squares (T2), four 4"x 4" squares (T3), and eight 4"x 4" squares (T4). There were two controls used in the study: a can control (CC) and pouch control (PC). The can control was used as an "ultimate" control, the standard to which the peaches in pouches were compared. The pouch control, an EVOH pouch containing no oxidation inhibiting material, was used to compare how well the varying levels of oxidation inhibitor preserved the peaches compared to the EVOH pouch alone.

The EVOH pouches stored at 25°C were used to approximate ambient temperatures. EVOH pouches stored at 35°C and 45°C were used to accelerate the shelf-life of the samples. Storage of all EVOH pouches took place in calibrated temperature controlled chambers with ambient, uncontrolled humidity at Westpak, Inc. (San Jose, CA). EVOH pouches stored at 45°C were to be aged for six months, samples at 35°C for one year and samples at 25°C for two years.

The 45°C samples were evaluated twice per week for color. No texture evaluations were done on these samples since the color darkened much more rapidly than expected (within two weeks of storage) and the samples reached the end of shelf-life condition after only four and a half weeks. The 35°C samples were evaluated weekly for color and monthly for texture. The 25°C samples were evaluated every two weeks for color and every eight weeks for texture. At each sample evaluation time, one pouch control and two oxidation inhibitor treatment EVOH pouches (one T1 and one T2) were examined. Beginning in week fifteen of the study, all sample pouches of each type were evaluated for color at each evaluation period. The texture evaluation schedule remained unchanged.

Manufacturer recommendations were followed to determine the amount of oxidation inhibiting material to be used in the pouches. According to the manufacturer, Mr. Bud Tollette of H. B. Tollette & Associates (Sacramento, CA), "the material should be about 50% in size of one side of the pouch." Since the finished size of the EVOH pouches used in the study were approximately 8"x10", it was thought that two 4"x 4" squares would be sufficient to show the efficacy of the material and that the single 4"x 4" square would provide a benefit somewhere between the pouch alone and the pouch with two 4"x 4" squares.

Since this was a new, previously untested technology, pouches to be evaluated toward the end of the study were given additional amounts of oxidation inhibiting material to guard against the possibility that the amount of material used initially was not sufficient. For weeks 80, 88, and 96 at the 25°C condition and weeks 40, 44, and 48 at the 35°C condition, two additional test conditions were added: 1) EVOH pouches containing four 4"x 4" squares of oxidation inhibiting material and 2) EVOH pouches containing eight 4"x 4" squares of oxidation inhibiting material. Beginning at week fifteen of the study, these treatment EVOH pouch samples were analyzed for color only.

Industry wide standards dictate that sensory qualities such as color and texture are used as main criteria when grading peach products and determining peach quality. Hence, color was the main quality criterion used to determine the end of shelf-life condition in this study. Texture evaluations were performed throughout the study to serve as further confirmation of quality loss in the peaches.

ANALYTICAL METHODS

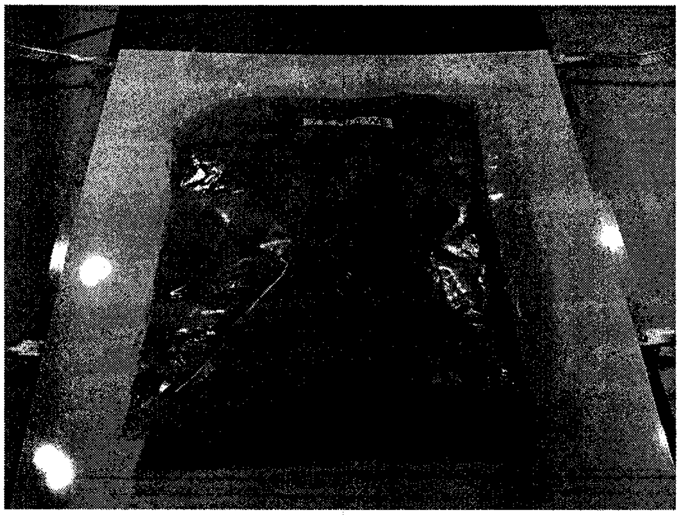
Color Evaluation

Light reflected from a colored object can be divided into three components which are termed hue, value and chroma. Hue refers to the color's wavelength in the electromagnetic spectrum. Every color in the visible portion of this spectrum can be created by adding red, green and blue light. Value refers to the lightness or darkness of a color relative to a gray scale starting with black at one end and ending with white at the other. Chroma refers to the intensity of the color. A three dimensional coordinate scale for describing color utilizes the attributes of lightness-darkness, yellowness-blueness, and redness-greenness. These dimensions of color used in tristimulus colorimetry can be quantified by an instrument such as the Hunterlab colorimeter. Within the food industry, the Hunterlab colorimeter is widely used for quantitative analysis on the color of food products. With digital photography, each photo is comprised of pixels and each pixel contains a red (R), green (G), and blue (B) color component. The RGB scale can then be used to quantitatively describe the color in any photograph. The common thread between these two methods is the measurement of hue. To analyze and document the color changes that took place during this study, digital photography was used.

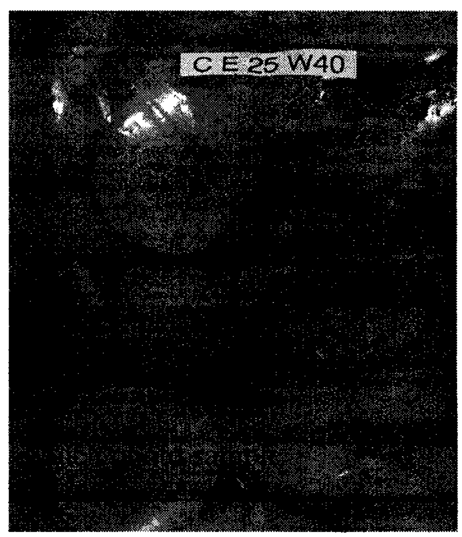
During a color evaluation, digital photos were taken with a Canon PowerShot A60 2.0 Mega pixel camera with a 5.4-16.2mm zoom lens. Adobe Photoshop CS version 8.0 was used to categorize and quantify the progression of color changes that took place. The end of shelf-life color condition was determined as being the point at which it was visibly evident that most of the peaches in a pouch had browned to an unacceptable level. This visual color was correlated to the photographs of the peaches. The endpoint was then defined quantitatively in the photographs by using the mean RGB levels found on Photoshop's Histogram palette. These mean levels represent the average intensity value of the pixels in the photo for that color channel. The actual endpoint values were an R (Red) level of 193.03, G (Green) level of 107.50, and a B (Blue) level of 25.26. The photography procedure was as follows:

1. Samples to be photographed were identified according to the schedule and pulled from the corresponding temperature controlled storage chamber.

2. Each pouch was individually photographed against a white background on a photography stand fitted with four General Electric BCA No. 1 blue photo flood bulbs (115 – 125V). The following photo shows the photography stand and the white background.



The camera was mounted directly above the sample and the zoom lens was used to maximize the pouch area in the photograph. When photographing peaches from a can, the samples were poured out into a glass container prior to being placed onto the light stand. The following photos show examples of the photographic data used in the study. This single orientation was used for all photos throughout the study. It was not possible to control for the position of each peach.



3. Photograph quality was verified and the pouches were returned to their appropriate shipping container and storage chamber.

4. All digital photographs taken were then downloaded to a DELL laptop PC where each photo was renamed incorporating the label identifier on the pouch and the date the photo was taken. All photos were then backed up onto compact discs in triplicate.

5. Each photograph was opened in Photoshop and using the Histogram palette, the average intensity value of the pixels in the entire photo for each of the RGB (red, green, and blue) color channels was obtained and recorded for each photo. These average intensity values will be referred to as the mean color index, i.e. mean red index.

6. The mean color indexes for each of the test conditions within a temperature condition were plotted against time. Regression analysis was performed using Minitab Release 14 and the best fit line was plotted with a 95% confidence interval. These graphs showed the progression of color change for each test condition at a particular storage temperature over time. To reduce bias when categorizing the RGB levels in a photo, the entire photo was used, not just selected areas. Therefore, the data points on the graphs represent the average value of that color channel for the entire pouch, not just any browned area(s). It is for this reason that the actual endpoint values for R, G, and B are not always reflected on the regression graphs.

7. The slopes of the regression lines for the PC, T1, T2, T3, and T4 test conditions at a given temperature condition for a particular color index (red, green, or blue) were compared in pairs. Using a t-statistic commonly used in biostatistical analysis when

comparing two treatment conditions, hypothesis testing on the equality of the slopes of all regression lines was performed. These calculations were performed using Microsoft Office Excel 2003.

Texture Evaluation

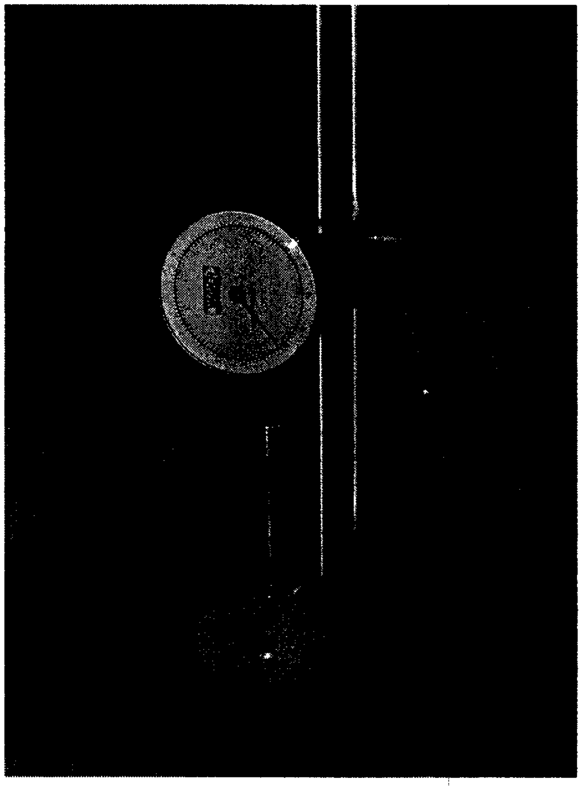
Texture evaluations were performed using a Wagner model FT 011 Fruit Tester fitted with a FT 516 (7/16" diameter) plunger and FTK Test Stand designed for peaches, melons, citrus, and soft fruits. During a texture evaluation, the non-pit side of each peach half in a sample was punctured with the fruit tester's plunger and the pressure used to pierce the flesh of the peach was recorded. Due to the softening caused by the second heat process the peaches were subjected to during the hot fill process used to pack the EVOH pouches, texture data points for the pouches are in a lower range than those for the can control. The texture evaluation procedure was as follows:

1. Samples to be evaluated were identified according to the schedule and pulled from the corresponding temperature controlled storage chamber.

2. The pouch or can was opened and the contents were placed into a strainer in a sink where the syrup was drained. The strainer containing the peach halves was then placed over a bucket and brought to the table where the fruit tester was available.

3. Working with one peach half at a time, each sample was placed onto a round, low-rimmed glass support dish with the pit side down. The dish was then placed onto the stand of the fruit tester and positioned so that the plunger of the fruit tester was approximately 2 inches directly above the center of the peach half.

4. The pressure gauge on the fruit tester was set to zero and using a two second



motion, the lever of the fruit tester was lowered until the plunger pierced the flesh of the peach half, but not so far as to touch the dish on the stand of the fruit tester.

5. The pressure reading was recorded and the pierced peach half was set aside. Once the reading for each peach half in a pouch or can was recorded, the pierced peach halves for that sample were discarded.

RESULTS AND DISCUSSION

The visual observations made throughout the shelf-life of the pouches in this study were the basis for the determination of the color changes that took place. These observations were then quantified by analytical and statistical methods which related the visual observations to graphical illustrations. In this study, the end of shelf-life criterion for color was judged to be when unacceptable color was visually observed on peaches throughout the pouch. Over time, it was observed that the color of the peaches in the pouches displayed a pattern of gradual, overall darkening until they suddenly reached a color deemed to be unacceptable. This unacceptable color was visible to human observers as a darker grayish-brown color on the surface of the peach halves.

This visual criterion was also defined quantitatively in terms of mean RGB levels as an R of 193.03, G of 107.50, and B of 25.26 using the Histogram palette in Adobe Photoshop. Since these mean levels represented the average intensity value of all of the pixels in the entire photo for that color channel and not just an area of unacceptable color, these exact levels are not always reflected on the best fit line plots shown in Figures 1 - 9. These figures show the regression line for each RGB color channel at each temperature condition. These regression figures can be used to illustrate the progression of color changes that occurred throughout the study and they allow for comparison among the treatment conditions. The use of regression analysis and subsequent comparisons on the slopes of the regression lines was thought to best reduce the effect of the wide, inherent variability in the color and texture of the peaches. Outliers in the samples contributed to variability in the data and were observed as peach halves with light yellow color and very firm texture.

The regression analysis can be directly related to the visual observations that took place. Table 2 shows the point at which the unacceptable color was first visually observed in a given pouch. Although the hypothesis testing on the slopes of the regression lines did not show any statistical significance at the T4 level, it was observed that at 25°C, unacceptable color did not appear in T3 and T4 pouches until week 48, the endpoint of the study at this temperature. However, unacceptable browning, the end of shelf-life color condition, was reached sooner than expected at all temperatures. The color criterion endpoint for the 45°C study was reached after 4.5 weeks, the endpoint for the 35°C study was reached after 21 weeks and the endpoint for the 25°C study was reached after 48 weeks.

Due to inconsistent photography methods used at the beginning of the study, some of the initial data points for color were not included in the regression analysis. In the 45°C study all of the photos were taken using the light stand without the camera mount. This was not ideal but all of the pictures taken of these samples were consistent with one another. In the 35°C and 25°C studies, the use of the light stand and camera mount began in week 7 and week 8 respectively. It is the data from these evaluation periods forward that were used for the regression analysis.

With regard to color, all of the peaches in the EVOH pouches darkened over time. As can be seen in Figures 1 – 3 for 45°C, Figures 4 - 6 for 35°C and Figures 7 - 9 for 25°C, in general, the mean red index values decreased over time and the mean blue index values increased over time in each temperature condition. This corresponded to the visual observation of overall darkening in the peaches. It was expected that the oxidation inhibitor material would prevent the onset of this darkening of color. In the study, the PC samples contained no oxidation inhibitor, T1 samples contained one 4"x 4" square, T2 samples contained two 4"x 4" squares, T3 samples contained four 4"x 4" squares, and T4 samples contained eight 4"x 4" squares.

To the human observer, the CC (can control) peaches at 25°C always appeared much brighter than any of the EVOH pouch samples. This was due, in part, to having been subjected to only a single heat process during canning as compared to the peaches packaged into the EVOH pouches which were subjected to a second heat process. In contrast to the oxidation treatment EVOH pouches which all showed an increase in mean blue color at 25°C, the CC samples showed a slight decrease. At this temperature, the CC, PC, T1, and T2 samples all showed a decrease in mean red color, and the mean green index increased slightly for all sample types except T4. At 35°C, mean red color decreased for all sample types except T4. Mean green color and mean blue color increased for all sample types at this temperature. At 45°C, mean red color decreased, mean blue color increased, and mean green color increased in the oxidation control but decreased in the T1 and T2 samples. In addition, it was observed that at 45°C, the oxidation treatment pouches obtained unacceptable color before the pouch control.

Tables 3 – 11 contain the t-values calculated to compare the slopes of the lines obtained from the regression analysis for red, green, and blue color at 25°C, 35°C, and 45°C. When these t-values were compared to the critical t-values during hypothesis testing, it indicated whether or not the slopes of the lines, or the rate of color change, were significantly different. A statistically significant difference in color change would indicate that the treatment had been effective. To further validate this method of comparison, it was expected that the can control would show a significant difference when compared to the pouches. Table 11 shows the significant differences found in mean blue color for the can control vs PC, T1, and T2 pouches at 25°C. Based on these results, statistical significance in blue color was a definite indication that the treatment had been effective.

Observations of the PC, T1, and T2 pouches did not reveal any discernible difference in color. These observations were directly reflected in the statistical analysis done on the RGB data from the pouch photos. Comparisons of the slopes of the lines from the regression analysis at each temperature show that with one exception, the PC, T1, and T2 samples did not differ significantly from each other. Therefore, the T1 and T2 levels of oxidation inhibitor did not effectively maintain the color of the peaches. Initially, it was the T2 level of oxidation inhibitor that was expected to inhibit browning in the peaches.

The one exception where this color analysis showed a significant difference was PC vs T1 Mean Blue Index at 25°C. At 25°C, the mean blue index increased more rapidly in the pouch control than it did in the T1 pouch. In this case, the oxidation inhibitor material slowed the rate of the increase in blue color of the T1 sample as compared to the pouch control and therefore kept the peaches from darkening more effectively than the pouch alone.

In the 25°C samples, there were significant differences in mean red and mean blue color for PC vs T3 and T2 vs T3. There were no significant differences in mean green color. Since the mean red index decreased for PC and T2 and increased for T3, and the mean blue index increased for PC and T2 and remained almost level for T3, this would indicate that the T3 level of oxidation inhibitor material helped maintain the color of the peaches It was observed that the T4 samples at 25°C appeared brighter than the PC, T1, T2, and T3 samples for a twelve week period during the study. During this time it was also observed that the T3 pouches appeared brighter than the PC, T1, and T2 pouches.

This occurred between weeks eighteen and thirty of the study. After this point, the T3 and T4 pouches darkened to approximately the same level as the T1 and T2 pouches. Figure 10 shows the regression lines at 25°C for the can control, pouch control, T1, T2, T3, and T4 pouches on the same graph for visual comparison of the effects of the treatments.

In the 35°C samples, there was a significant difference in mean green color for PC vs T4. However, it was unusual to have a high rate of increase in green color as exhibited in the T4 condition. This could be due, in part, to the smaller sample size of the T4 pouches and skewing of the data. It was observed that the T3 and T4 samples looked much brighter than the PC, T1, and T2 samples until week seventeen of the study. At this point, there were several T3 samples which appeared to be approaching the endpoint condition. Other T3 samples, however, remained more brightly colored.

With regard to texture, all of the samples softened over time. It was expected that the oxidation inhibiting material would help preserve the texture of the peach halves throughout the shelf-life of the product. Figures 11 and 12 show the mean textures of the can control as compared to that of the PC, T1, and T2 samples at 25°C and 35°C. Definitive trends in texture for any of the test conditions are not evident from these graphs. This could be due, in part, to the wide textural variability inherent in peaches. Due to the application of a single heat process as compared to the double heat process applied to the oxidation treatment pouches, the texture of the peaches in the can controls was in a higher range.

CONCLUSION

Different levels of oxidation inhibiting material were evaluated for their effect on color and texture in peach halves packaged in an active EVOH pouch. In this study it was found that the oxidation inhibiting material increased the shelf-life of the peach halves based on significant differences found in the mean red and blue color of the T3 oxidation treatment pouches at 25°C. For several weeks during the course of the study, pouches with the T3 and T4 levels of oxidation inhibitor appeared to have a much brighter color than samples with lower levels of oxidation inhibitor at this temperature. However, although the T3 and T4 levels of oxidation inhibitor were observed to have a preservation effect on the color of the peaches, it may not be desirable to use this oxidation inhibiting material at these high levels. The T3 and T4 pouches were observed to have a metallic odor and it is therefore possible that the packaging system had a negative effect on the product. In addition, these samples did eventually darken to almost the same degree as the samples with lower levels of oxidation inhibitor.

Circumstances which could have affected the results of this study may have been the spoilage of the product in the EVOH pouches. This caused a reduction in the number of samples available for evaluation and could have also affected the observations themselves. Certain spoilage organisms produce chemical compounds which may have had a bleaching effect on the color of the peaches.

Additionally, it was noted that data from this study displayed substantial variability. This could have been caused by two main factors: 1) the use of only a single photo of each sample at each color evaluation, and 2) and the inability to control the position of each peach in a sample pouch from week to week. The color properties of single peach halves are very different from one side to the other. Perhaps photographing both sides of the pouch and then averaging the RGB values together would have produced less variability and more continuity in the data. Reducing this variability would be an important factor in any future study.

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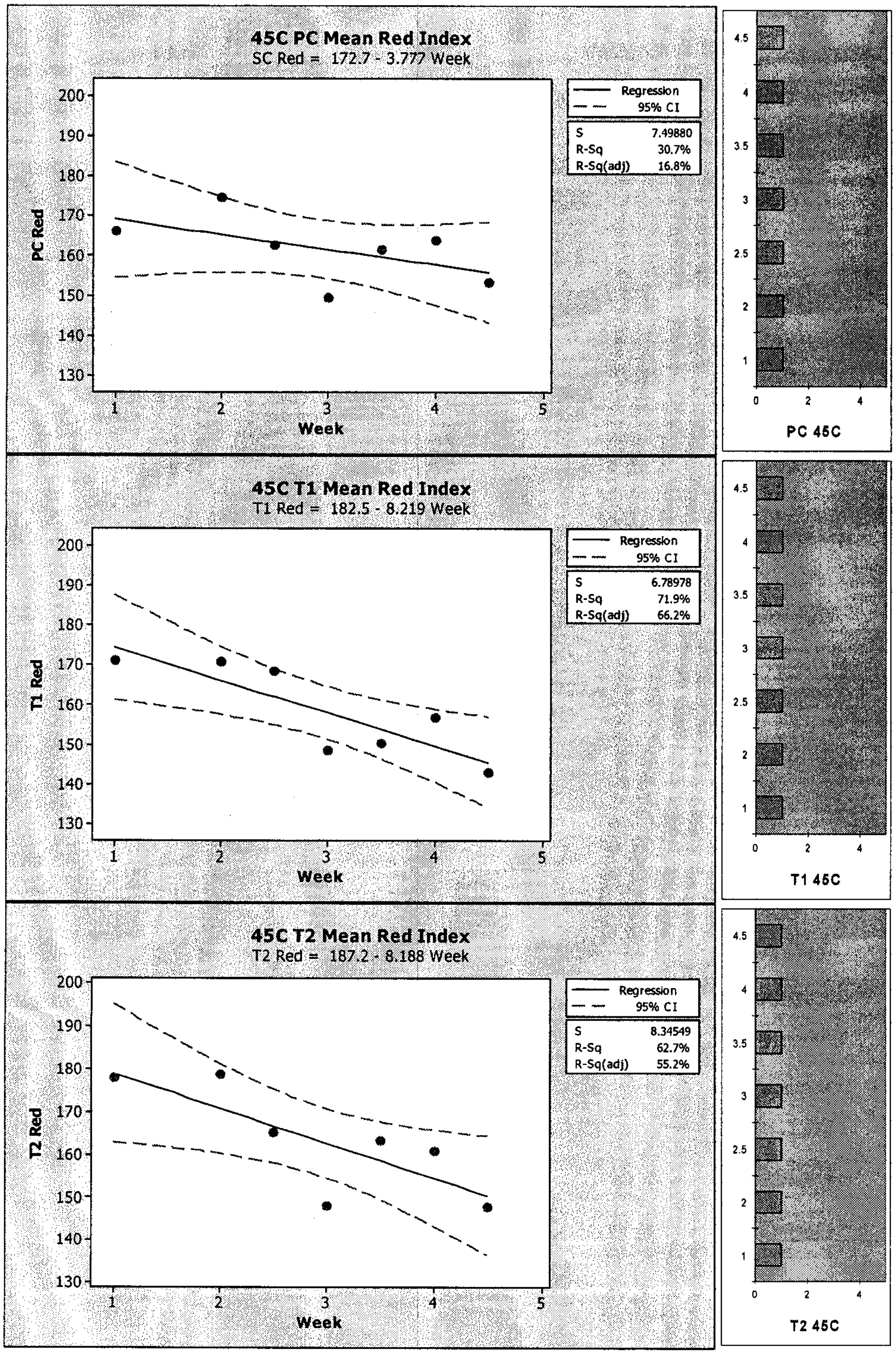
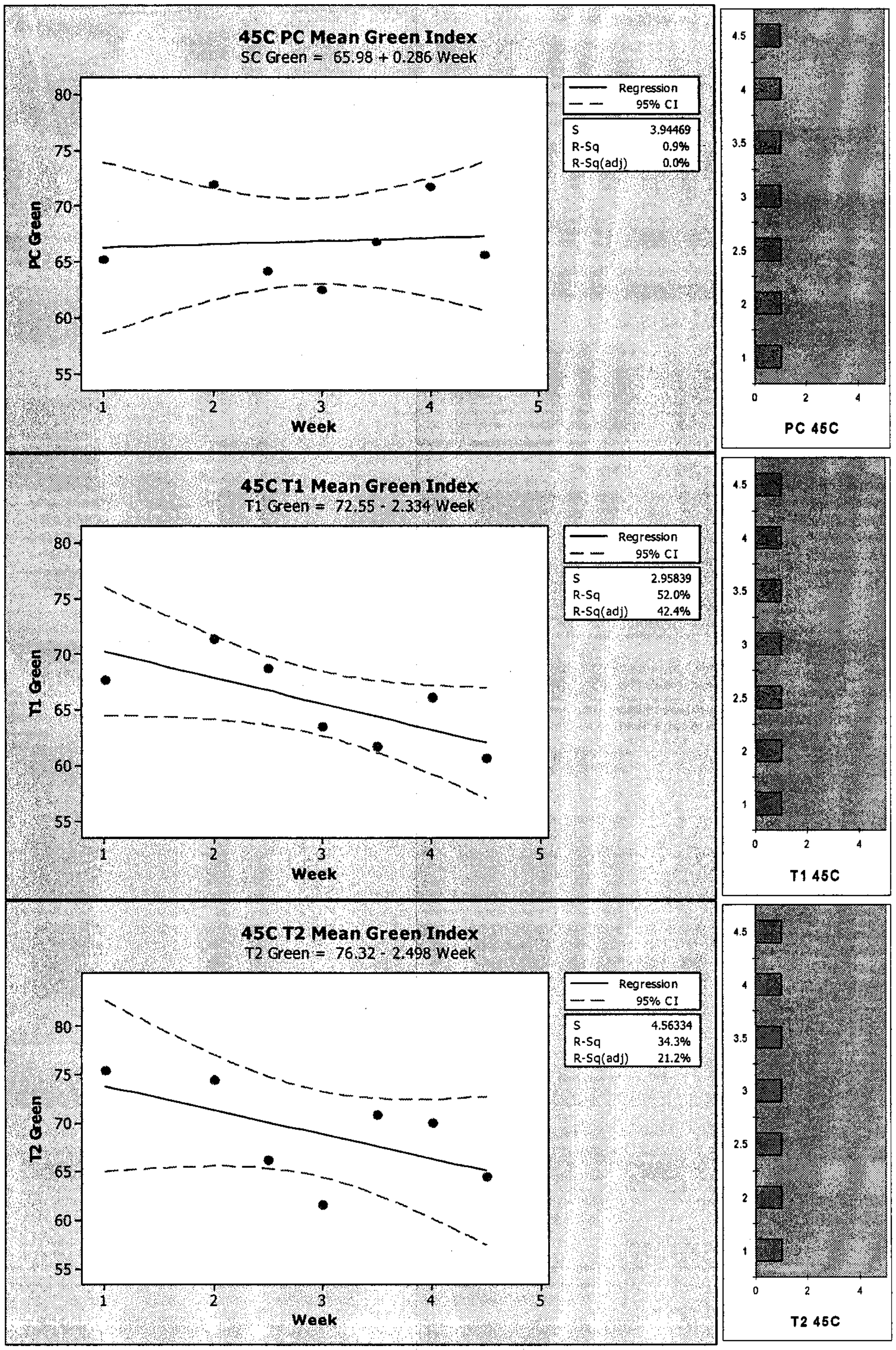
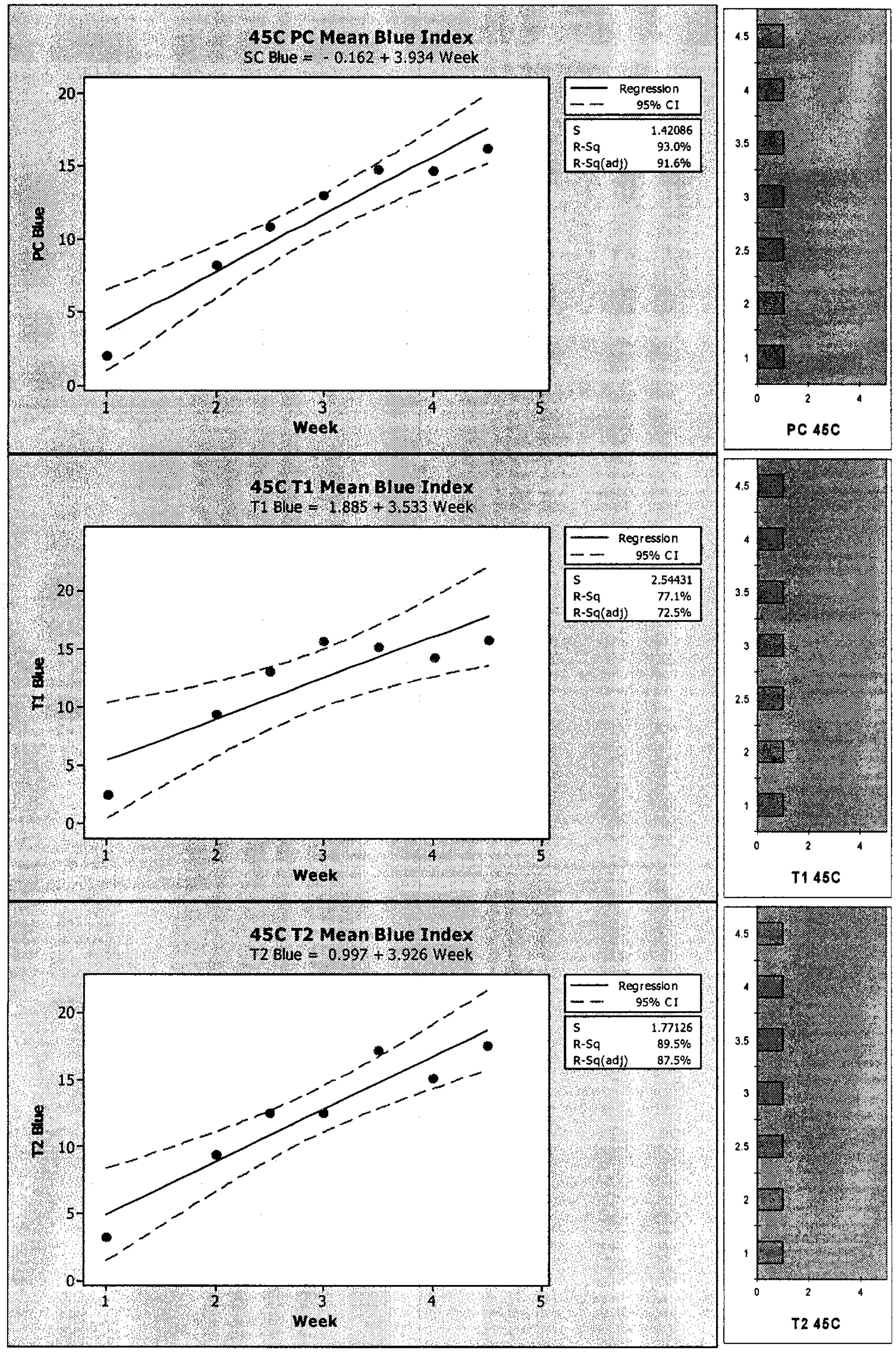


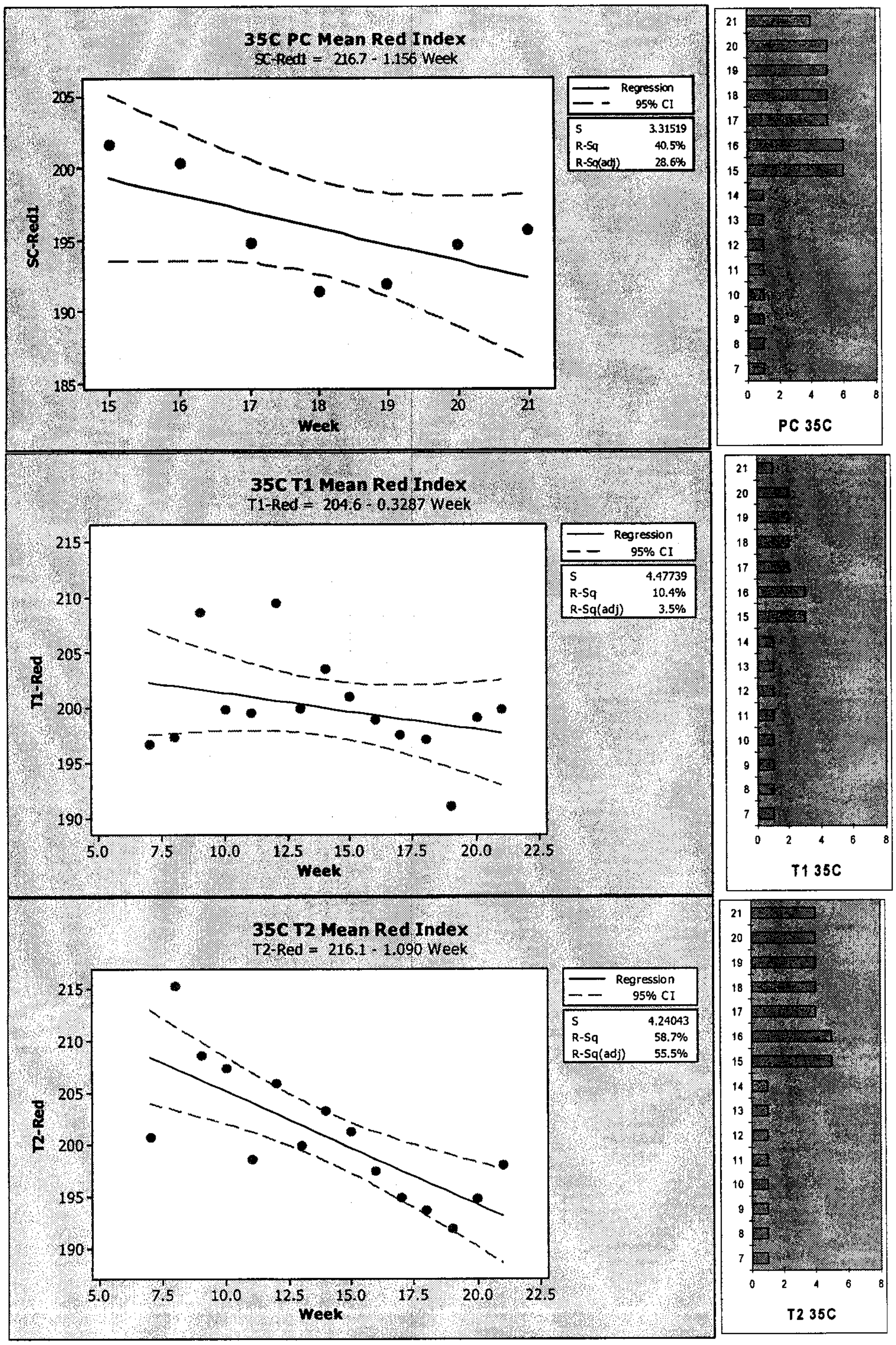
Figures 1A, 1B, 1C. Fitted Line Plot of Mean Red Index of PC, T1, and T2 at 45°C. The histogram to the right of each graph reflects the n value for each data point.



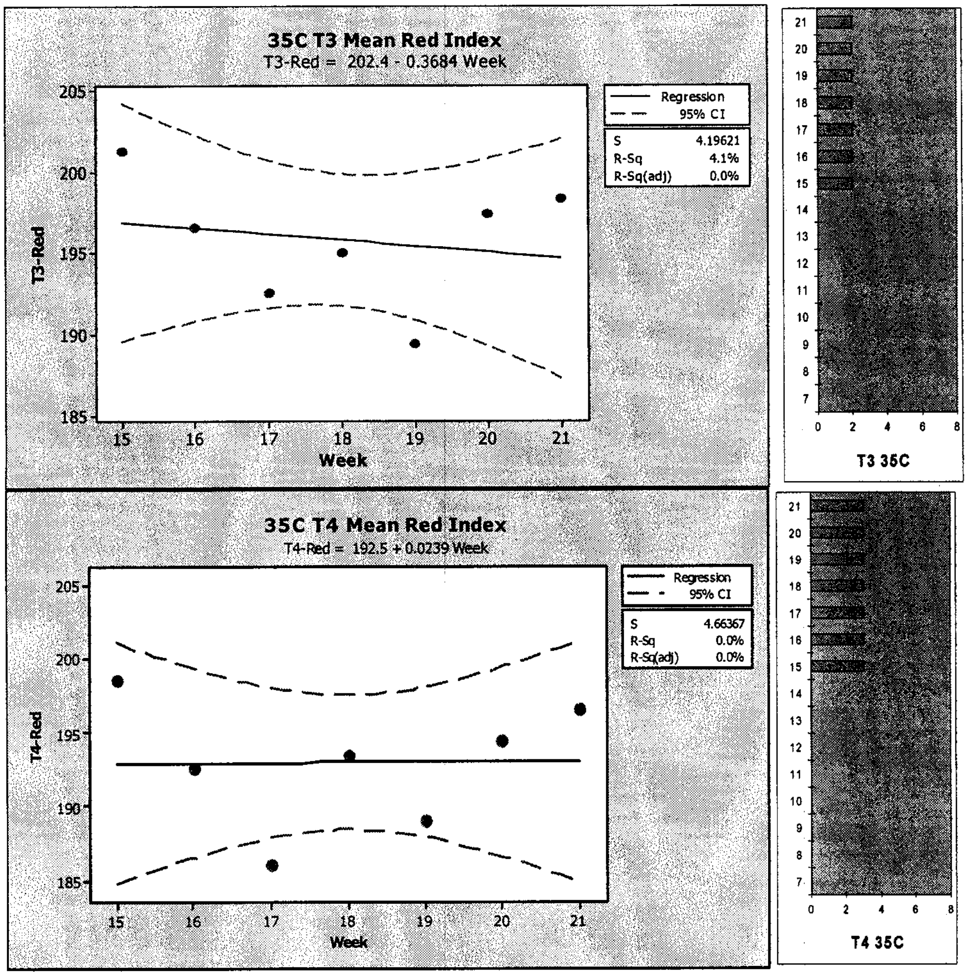
Figures 2A, 2B, 2C. Fitted Line Plot of Mean Green Index of PC, T1, and T2 at 45°C. The histogram to the right of each graph reflects the n value for each data point.



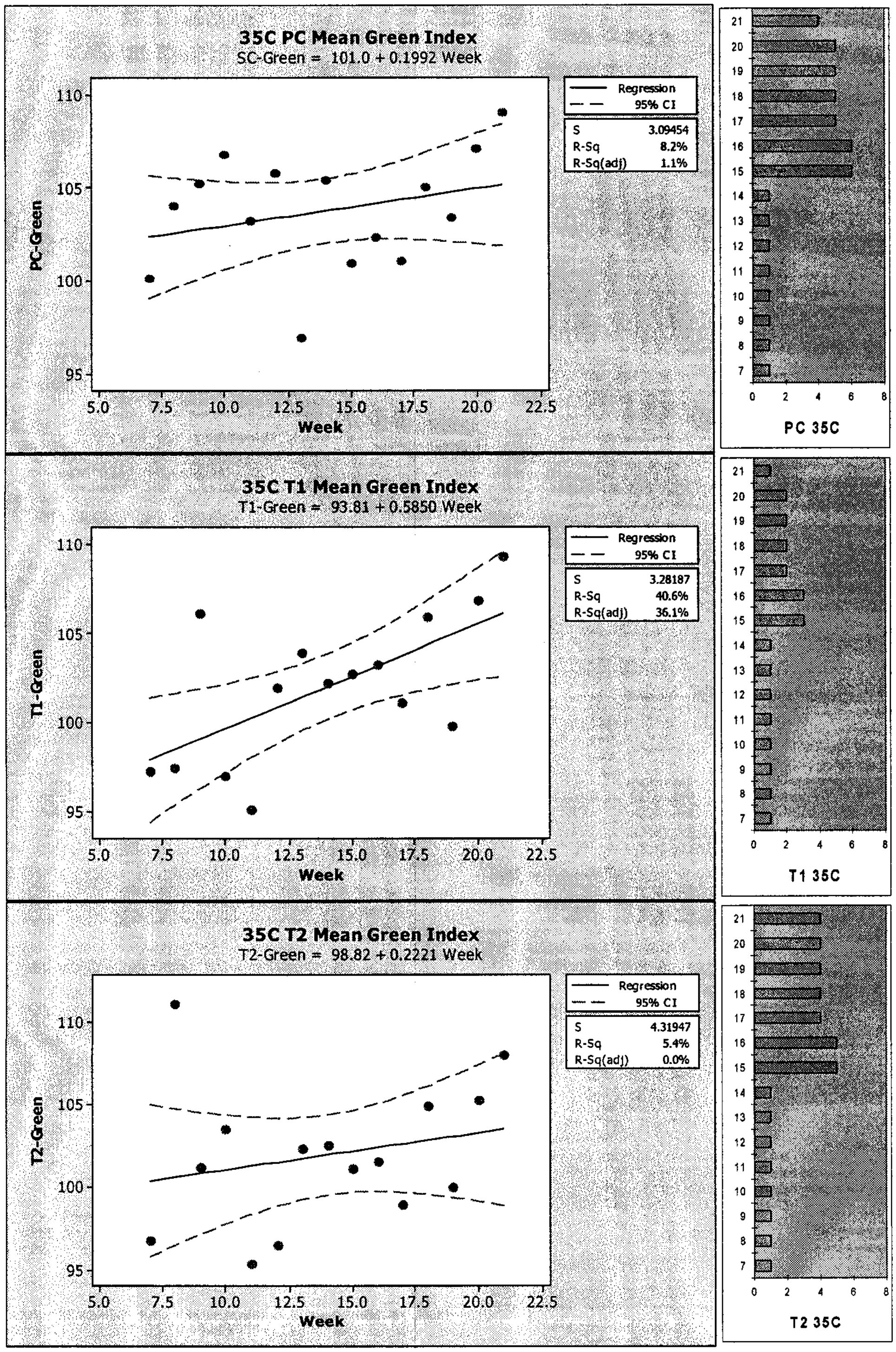
Figures 3A, 3B, 3C. Fitted Line Plot of Mean Blue Index of PC, T1, and T2 at 45°C. The histogram to the right of each graph reflects the n value for each data point.



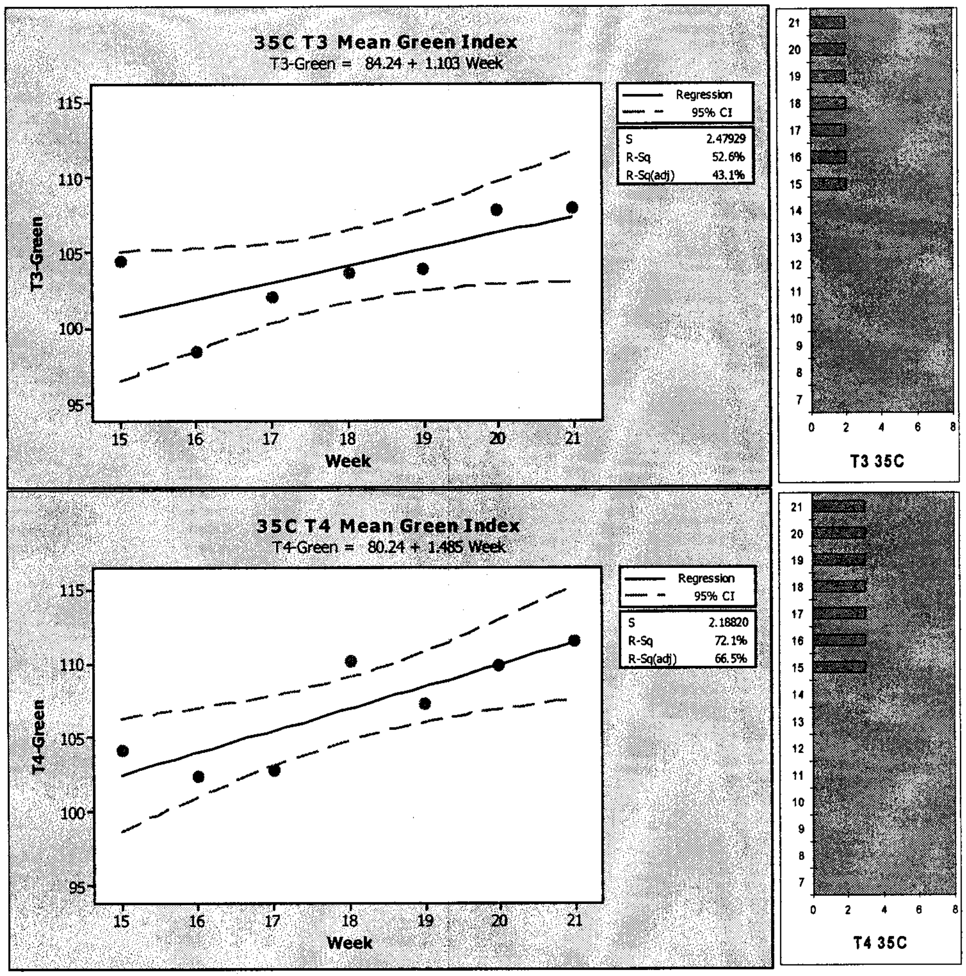
Figures 4A, 4B, 4C. Fitted Line Plot of Mean Red Index of PC, T1, and T2 at 35°C. The histogram to the right of each graph reflects the n value for each data point.



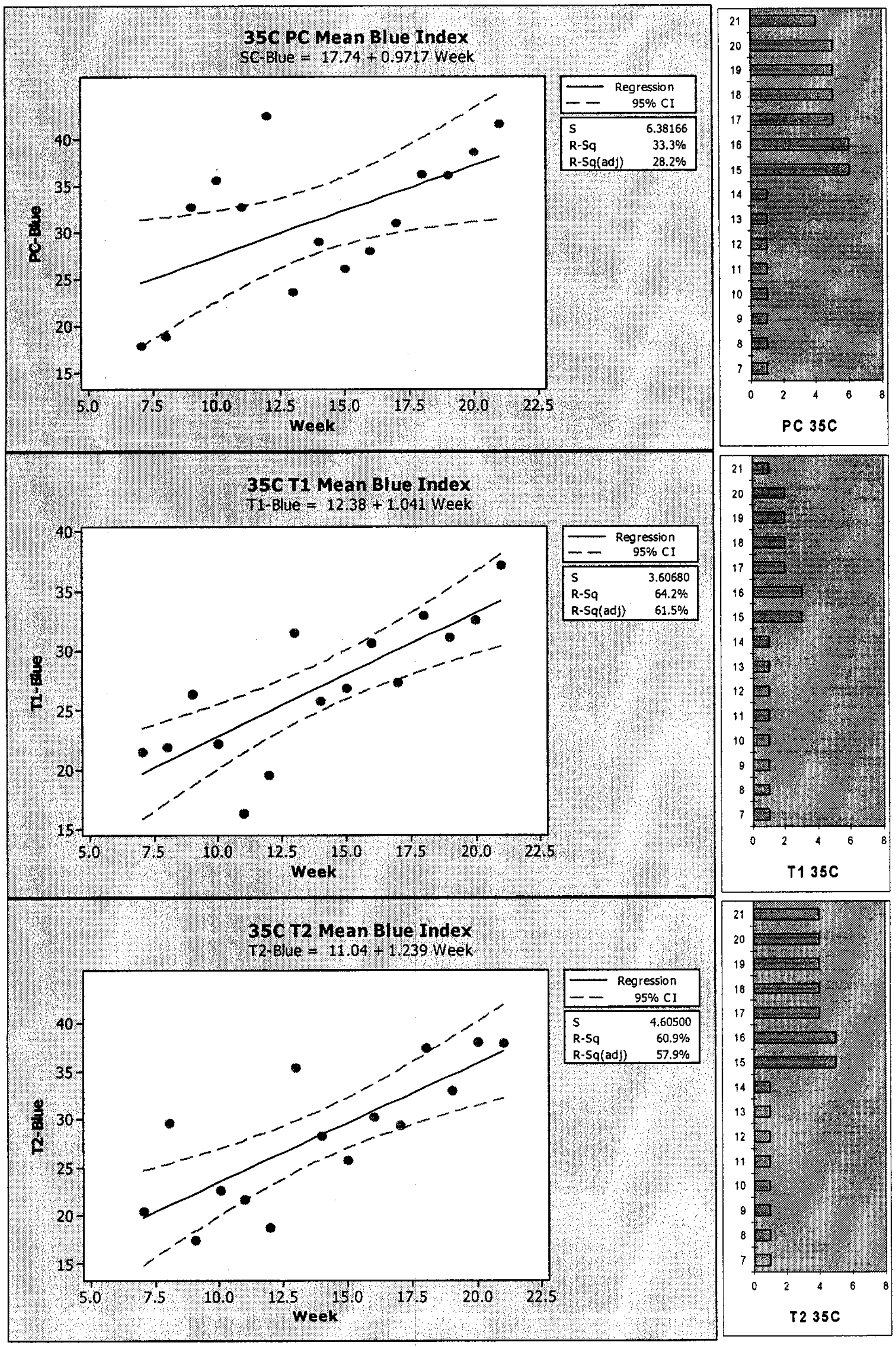
Figures 4D, 4E. Fitted Line Plot of Mean Red Index of T3 and T4 at 35°C. The histogram to the right of each graph reflects the n value for each data point.



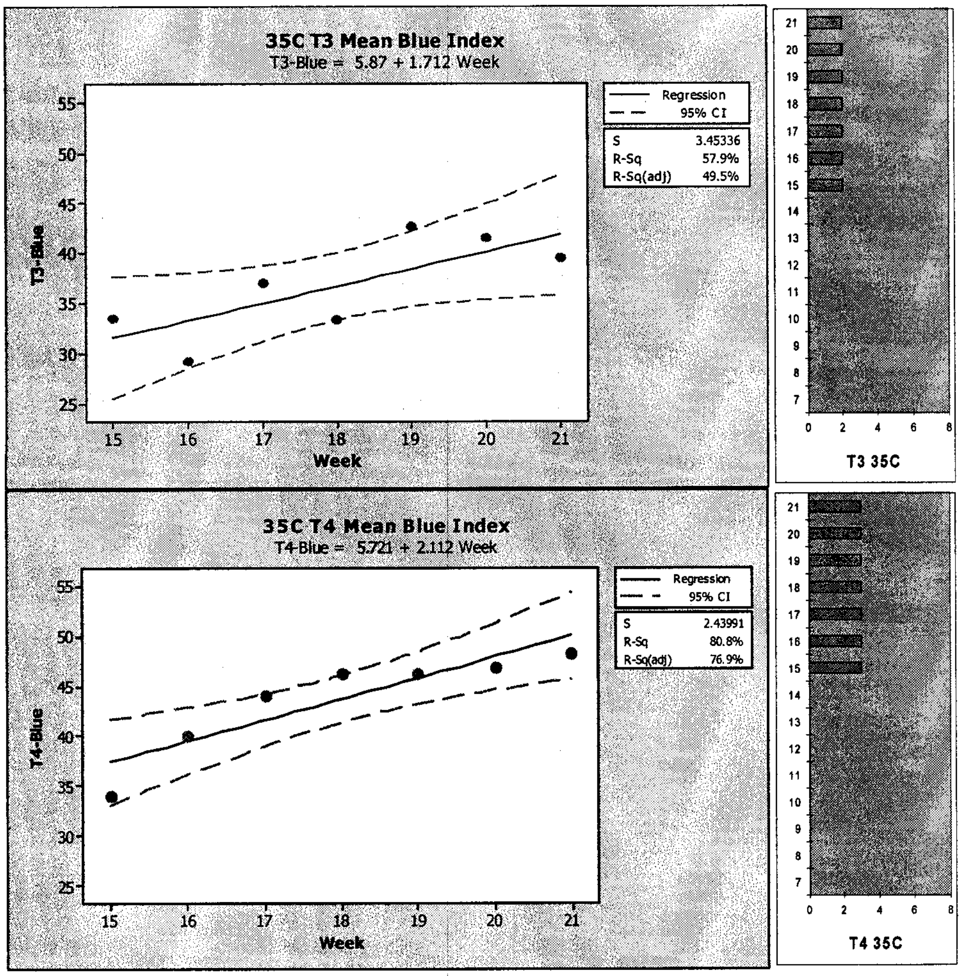
Figures 5A, 5B, 5C. Fitted Line Plot of Mean Green Index of PC, T1, and T2 at 35°C. The histogram to the right of each graph reflects the n value for each data point.



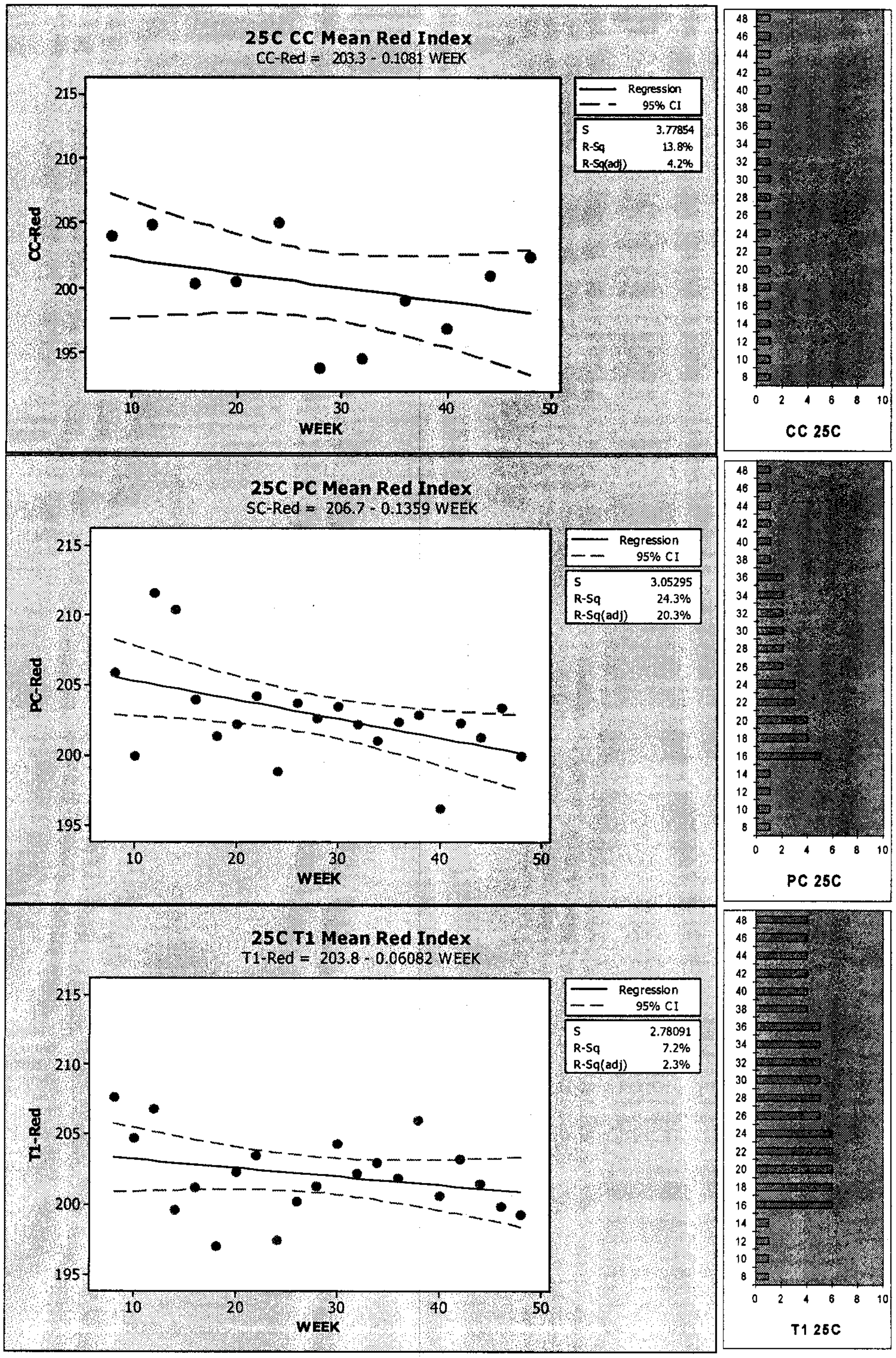
Figures 5D, 5E. Fitted Line Plot of Mean Green Index of T3 and T4 at 35°C. The histogram to the right of each graph reflects the n value for each data point.



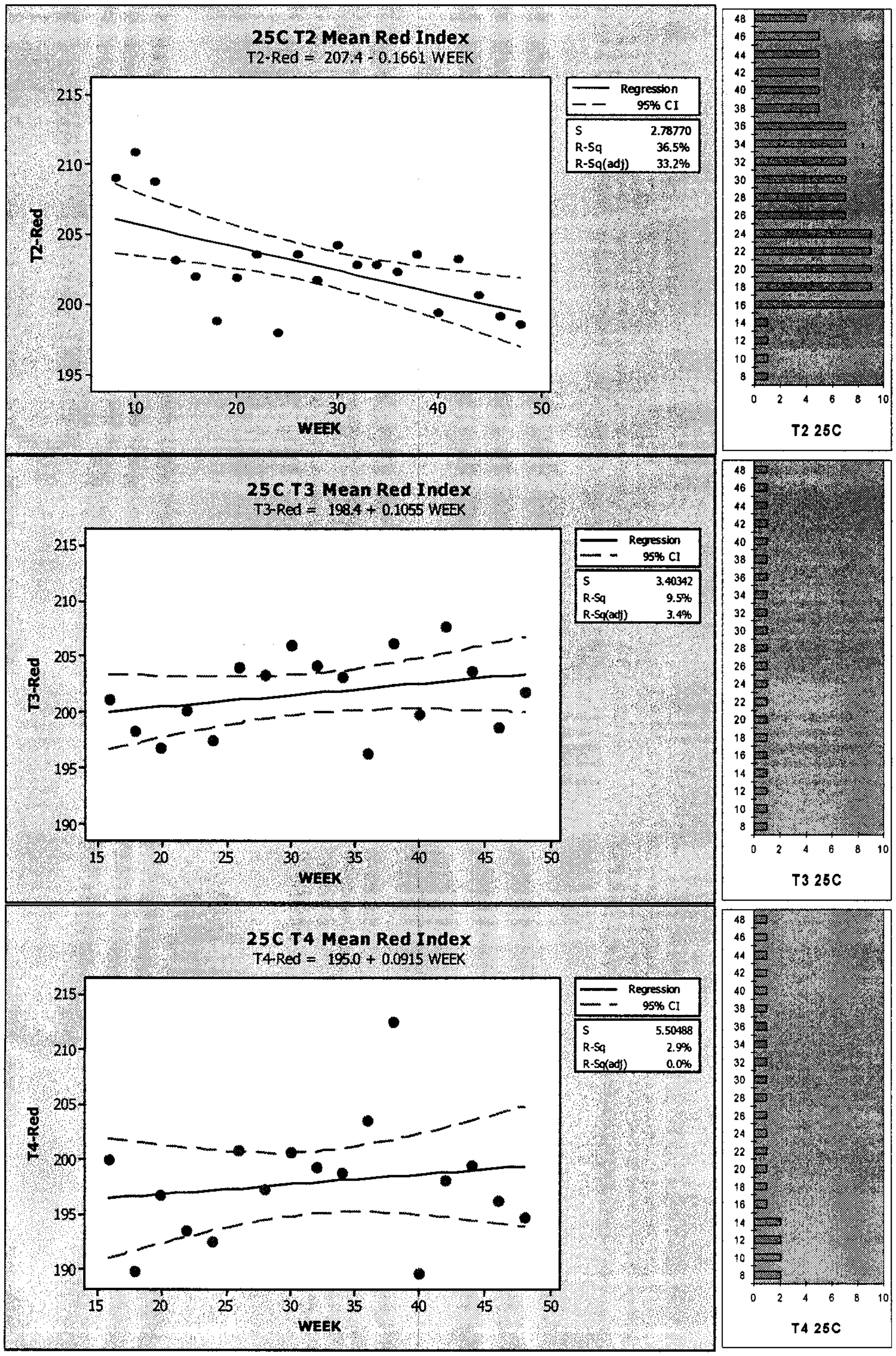
Figures 6A, 6B, 6C. Fitted Line Plot of Mean Blue Index of PC, T1, and T2 at 35°C. The histogram to the right of each graph reflects the n value for each data point.



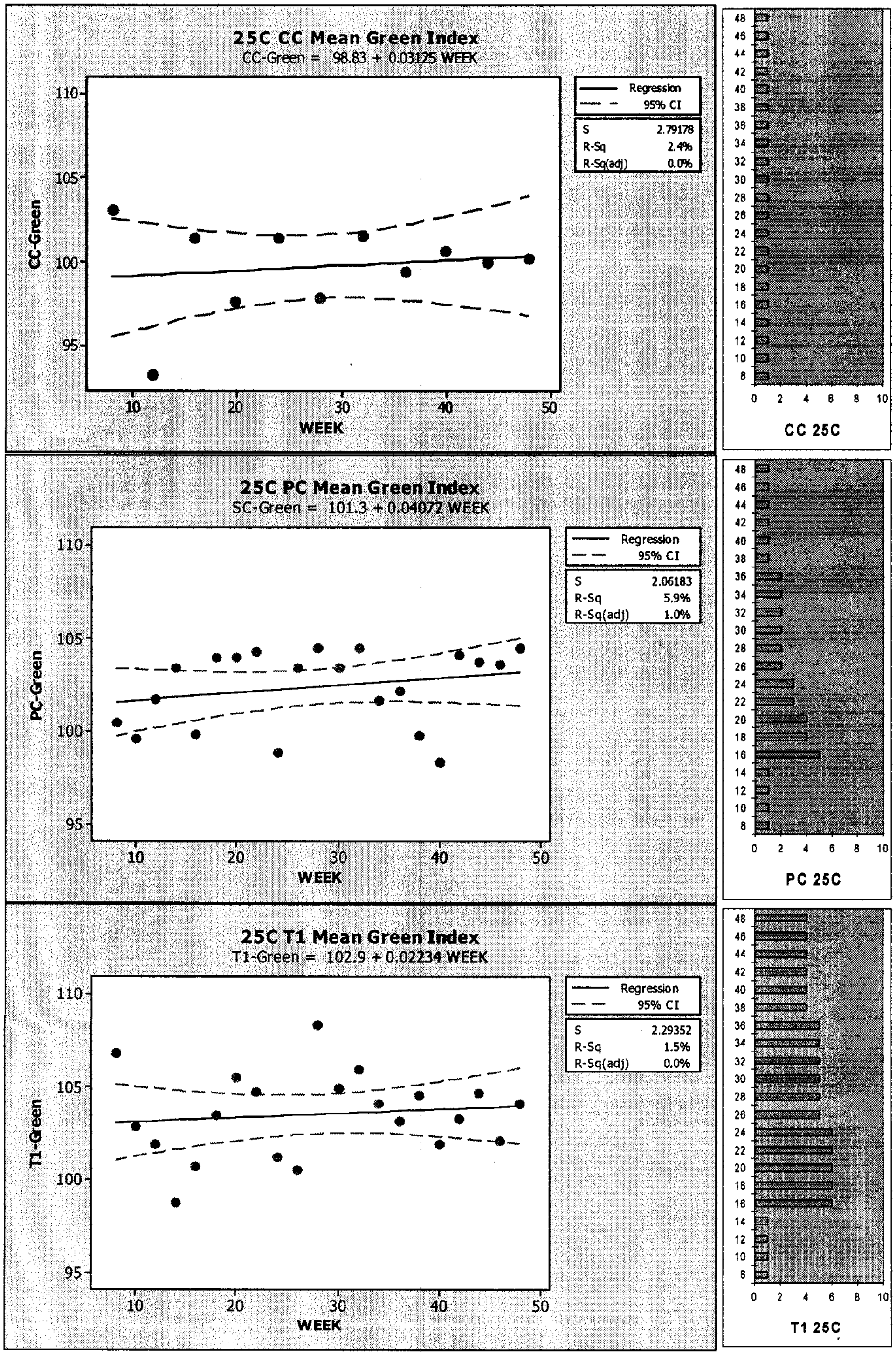
Figures 6D, 6E. Fitted Line Plot of Mean Blue Index of T3 and T4 at 35°C. The histogram to the right of each graph reflects the n value for each data point.



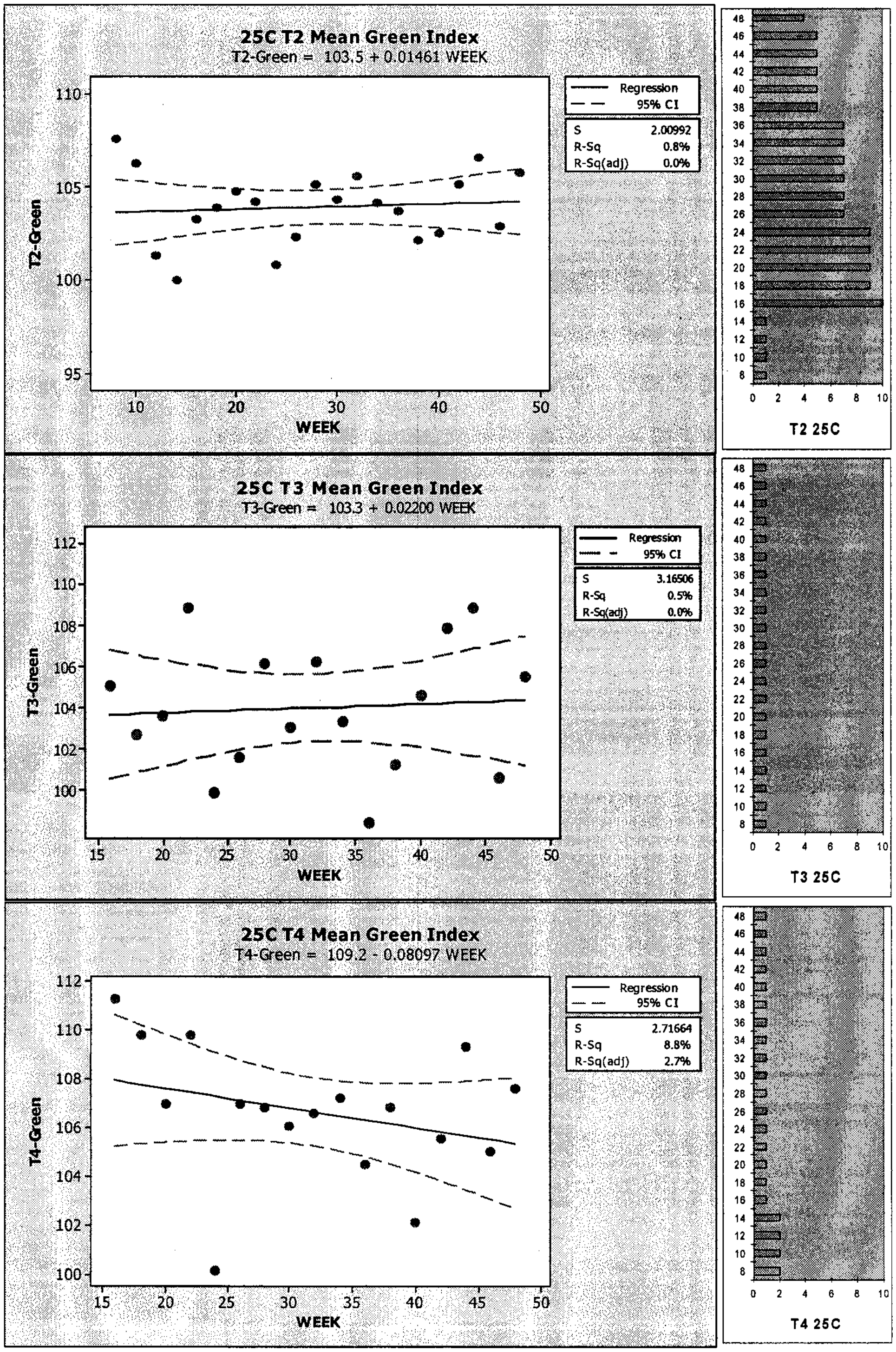
Figures 7A, 7B, 7C. Fitted Line Plot of Mean Red Index of CC, PC, and T1 at 25°C. The histogram to the right of each graph reflects the n value for each data point.



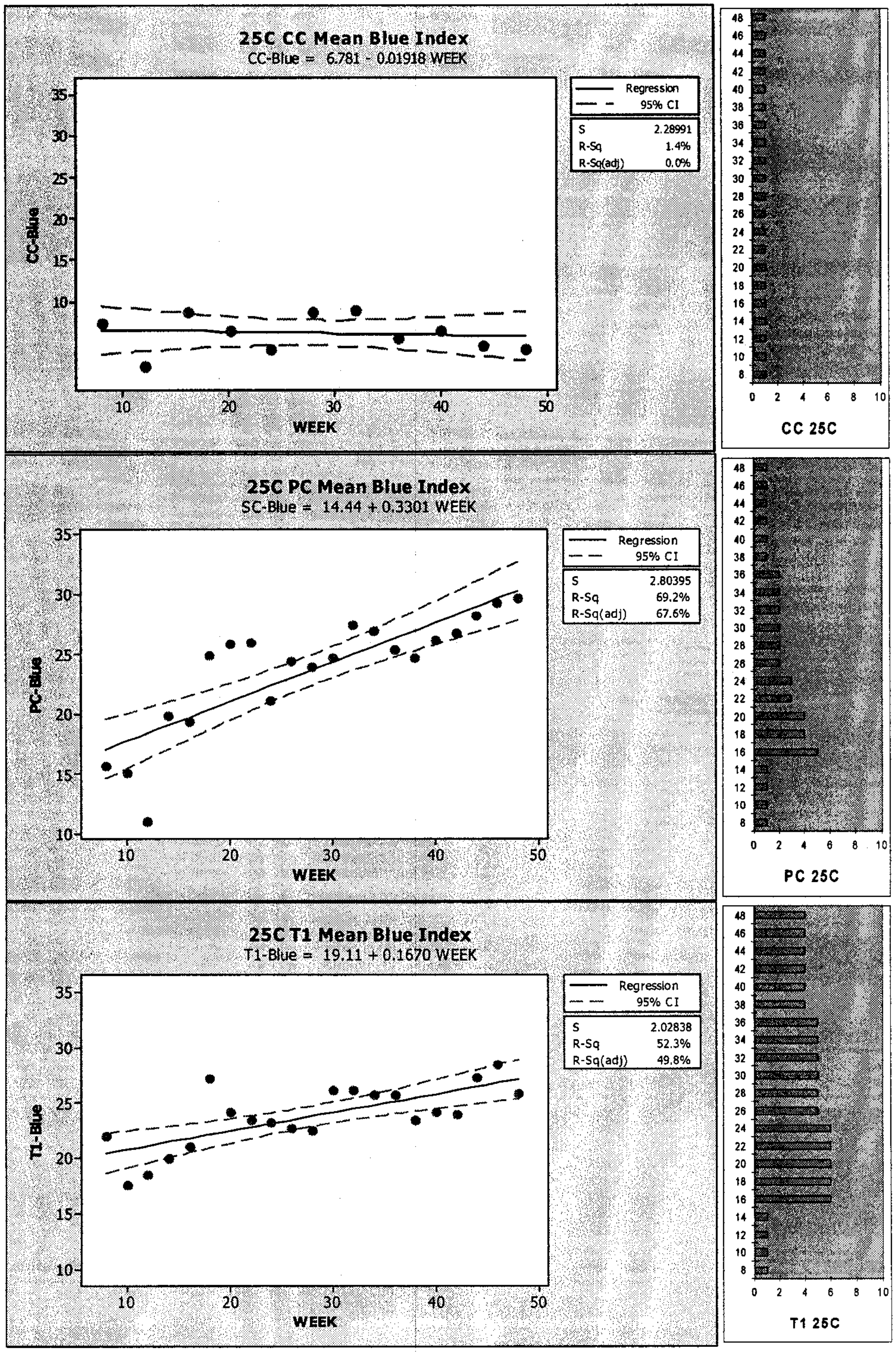
Figures 7D, 7E, 7F. Fitted Line Plot of Mean Red Index of T2, T3, and T4 at 25°C. The histogram to the right of each graph reflects the n value for each data point.



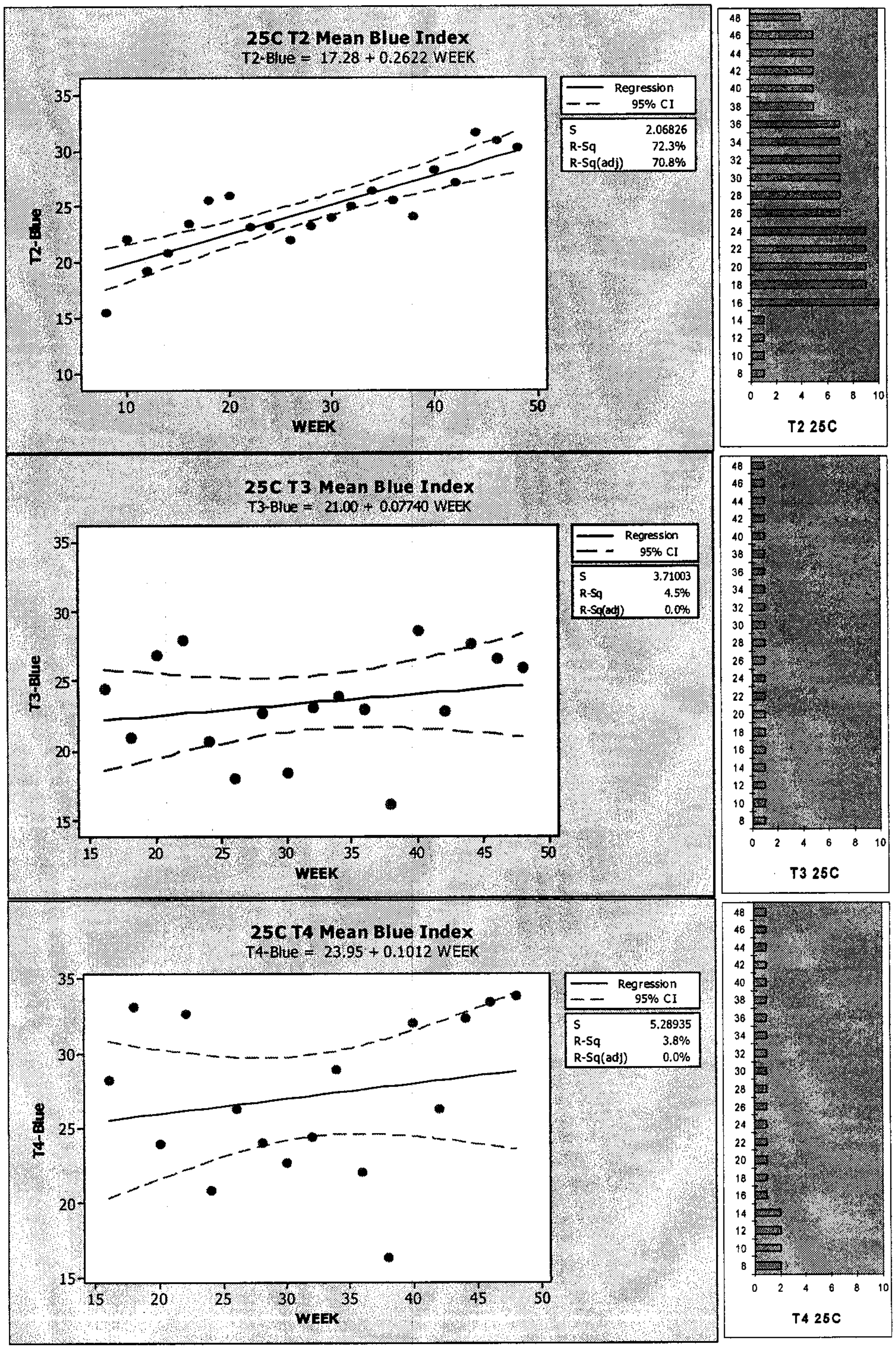
Figures 8A, 8B, 8C. Fitted Line Plot of Mean Green Index of CC, PC, and T1 at 25°C. The histogram to the right of each graph reflects the n value for each data point.



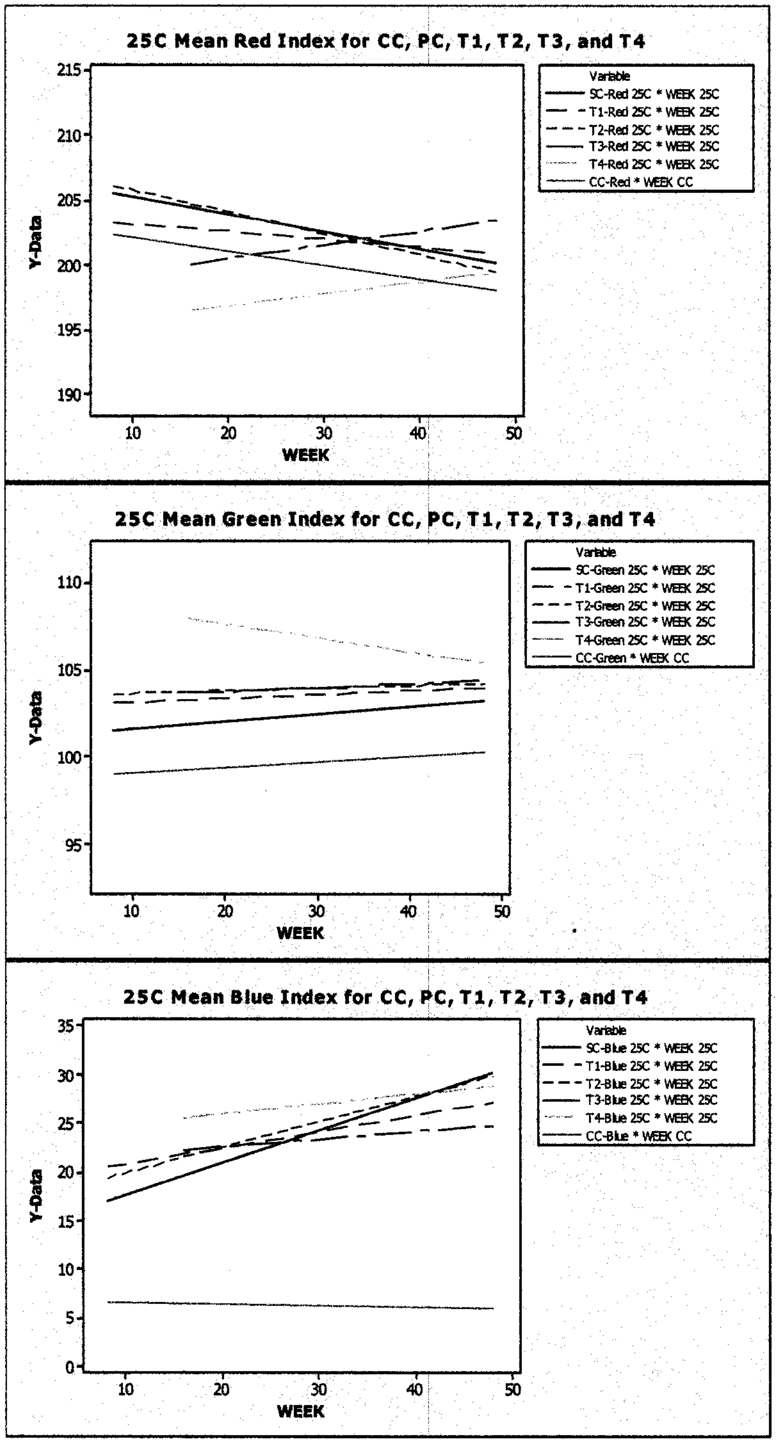
Figures 8D, 8E, 8F. Fitted Line Plot of Mean Green Index of T2, T3, and T4 at 25°C. The histogram to the right of each graph reflects the n value for each data point.



Figures 9A, 9B, 9C. Fitted Line Plot of Mean Blue Index of CC, PC, and T1 at 25°C. The histogram to the right of each graph reflects the n value for each data point.



Figures 9D, 9E, 9F. Fitted Line Plot of Mean Blue Index of T2, T3, and T4 at 25°C. The histogram to the right of each graph reflects the n value for each data point.



<u>Interpretation</u>:

All sample types showed a decrease in red color except for T3 and T4, which showed an increase compared to the other samples.

<u>Interpretation</u>:

All sample types showed a marginal increase in green color except for T4 which decreased compared to the other samples. CC had the least green color compared to the other samples.

<u>Interpretation</u>:

All samples showed an increase in blue color with PC increasing at the fastest rate. CC had considerably less blue color compared to all of the other samples.

Figure 10. Fitted Line Plots of Mean Red, Green, and Blue Index of CC, PC, T1, T2, T3, and T4 at 25°C

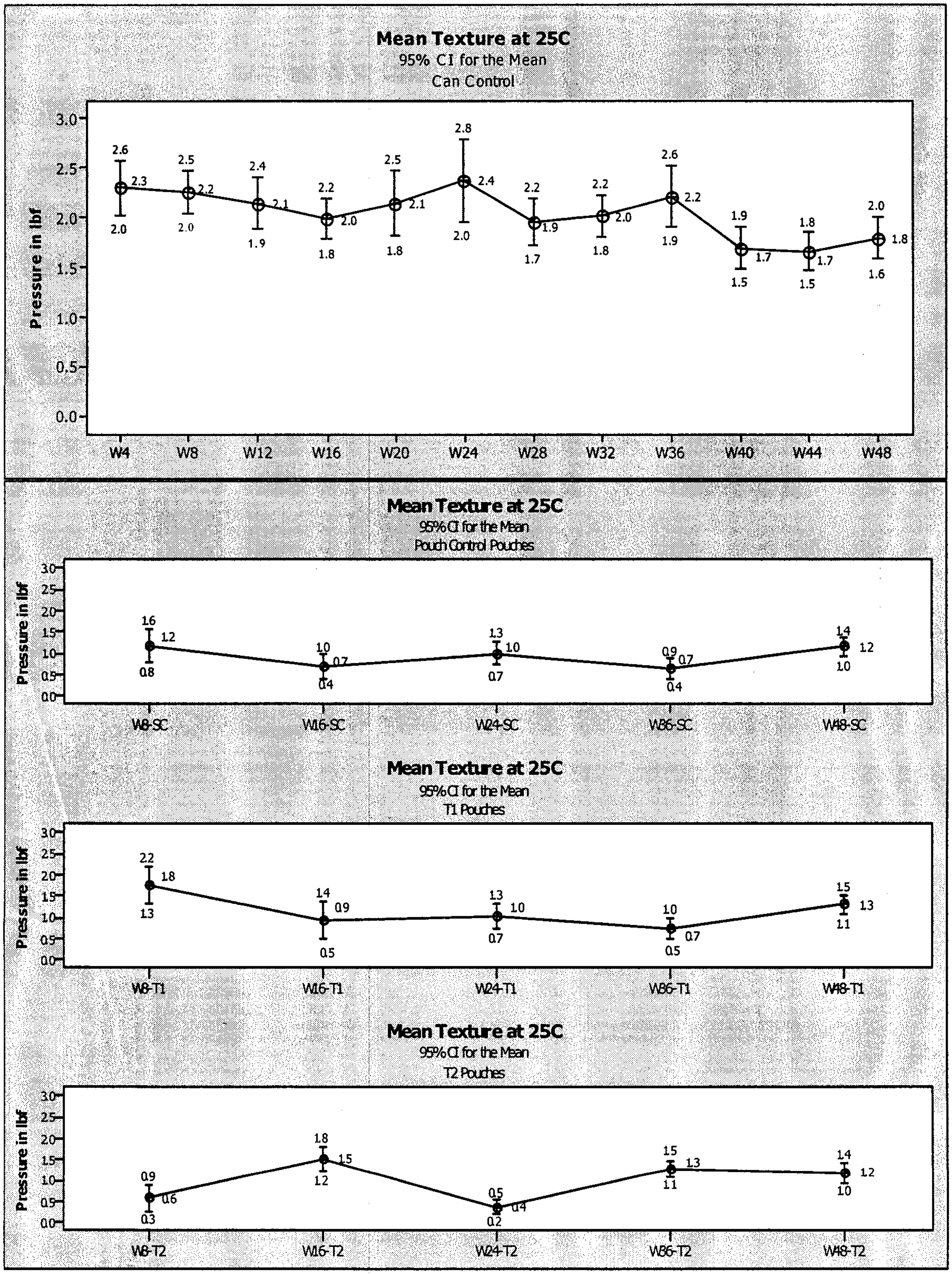


Figure 11. Mean Texture of CC, PC, T1, and T2 pouches at 25°C.

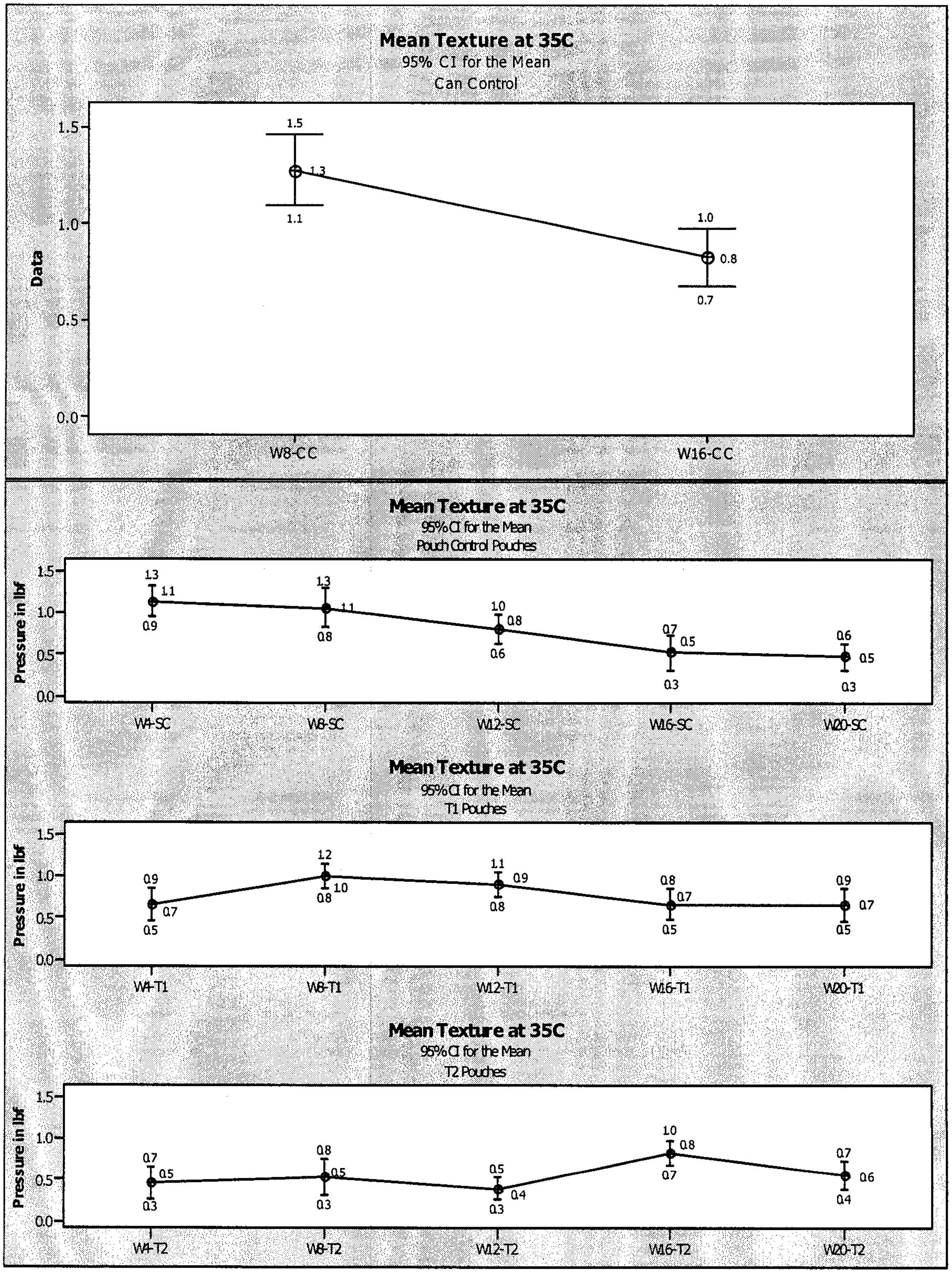


Figure 12. Mean Texture of CC, PC, T1, and T2 pouches at 35°C.

	PC	T1	T2	T3	T4
25°C	36	34	42	48	48
35°C	11	14	15	16	15
45°C	2	1.5	1.5		

Table 2. Time in weeks until first detection of unacceptable browning in oxidation inhibitor treatment pouches at 25°C, 35°C, and 45°C.

	T1 (Figure 1B)	T2 (Figure 1C)
PC (Figure 1A)	1.2962	1.1605
T1		-0.0085

Table 3. Calculated T values from regression analysis of Mean Red Index at 45°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1+n2-4}$ or $t_0 < -t_{\alpha/2,\, n1+n2-4}$

PC vs T1, PC vs T2, T1 vs T2; Total DF = 10, T = 2.2281

No significant differences.

	T1 (Figure 1B)	T2 (Figure 1C)
PC (Figure 1A)	1.5687	1.3626
T1		0.0890

Table 4. Calculated T values from regression analysis of Mean Green Index at 45°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1+n2-4}$ or $t_0 < -t_{\alpha/2,\, n1+n2-4}$

PC vs T1, PC vs T2, T1 vs T2; Total DF = 10, T = 2.2281

No significant differences.

	T1 (Figure 1B)	T2 (Figure 1C)
PC (Figure 1A)	0.4061	0.0109
T1		-0.3738

Table 5. Calculated T values from regression analysis of Mean Blue Index at 45°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1 + n2 - 4}$ or $t_0 < -\, t_{\alpha/2,\, n1 + n2 - 4}$

PC vs T1, PC vs T2, T1 vs T2; Total DF = 10, T = 2.2281

No significant differences.

	T1 (Figure 4B)	T2 (Figure 4C)	T3 (Figure 4D)	T4 (Figure 4E)
PC (Figure 4D)	-0.9904	1.1467	-0.3924	-0.8492
T1		2.0539	0.0455	-0.3921
T2			-0.8567	-1.2844
T3				-0.3303

Table 6. Calculated T values from regression analysis of Mean Red Index at 35°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1 + n2 - 4}$ or $t_0 < -t_{\alpha/2,\, n1 + n2 - 4}$

PC vs T1, PC vs T2, T1 vs T2; Total DF = 26, T = 2.0555

PC vs T3, PC vs T4, T1 vs T3, T1 vs T4, T2 vs T3, T2 vs T4; Total DF = 18, T = 2.1009

T3 vs T4; Total DF = 10, T = 2.2281

No significant differences.

	T1 (Figure 5B)	T2 (Figure 5C)	T3 (Figure 5D)	T4 (Figure 5E)
PC (Figure 5A)	-1.4565	-0.0708	-1.6069	*-2.3411
T1		1.1185	-0.8488	-1.5034
T2			-1.1406	-1.6550
T3				-0.6102

Table 7. Calculated T values from regression analysis of Mean Green Index at 35°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2, n1 + n2 - 4}$ or $t_0 < -t_{\alpha/2, n1 + n2 - 4}$

PC vs T1, PC vs T2, T1 vs T2; Total DF = 26, T = 2.0555

PC vs T3, PC vs T4, T1 vs T3, T1 vs T4, T2 vs T3, T2 vs T4; Total DF = 18, T = 2.1009

T3 vs T4; Total DF = 10, T = 2.2281

* Significant difference

	T1 (Figure 6B)	T2 (Figure 6C)	T3 (Figure 6D)	T4 (Figure 6E)
PC (Figure 6B)	-0.1578	-0.5684	-0.6530	-1.0312
T1		-0.5668	-0.9499	-1.6241
T2			-0.5530	-1.0680
T3				-0.4992

Table 8. Calculated T values from regression analysis of Mean Blue Index at 35°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2, n1 + n2 - 4}$ or $t_0 < -t_{\alpha/2, n1 + n2 - 4}$

PC vs T1, PC vs T2, T1 vs T2; Total DF = 26, T = 2.0555

PC vs T3, PC vs T4, T1 vs T3, T1 vs T4, T2 vs T3, T2 vs T4; Total DF = 18, T = 2.1009

T3 vs T4; Total DF = 10, T = 2.2281

No significant differences.

	PC (Figure 7B)	T1 (Figure 7C)	T2 (Figure 7D)	T3 (Figure 7E)	T4 (Figure 7F)
CC (Figure 7A)	0.2811	-0.5044	0.6191	-1.7515	-1.1791
PC		-1.0082	0.4074	*-2.4539	-1.7236
T1			1.4851	-1.7691	-1.1838
T2				*-2.8860	-2.0007
T3					0.0866

Table 9. Calculated T values from regression analysis of Mean Red Index at 25°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1 + n2 - 4}$ or $t_0 < -t_{\alpha/2,\, n1 + n2 - 4}$

PC vs T1, PC vs T2, and T1 vs T2; Total DF = 38, T = 2.0244

PC vs T3, PC vs T4, T1 vs T3, T1 vs T4, T2 vs T3, T2 vs T4; Total DF = 34, T = 2.0322

T3 vs T4; Total DF = 30, T = 2.0423

CC vs PC, CC vs T1, CC vs T2; Total DF = 28, T = 2.0484

CC vs T3, CC vs T4; Total DF = 24, T = 2.0639

* Significant difference

	PC (Figure 8B)	T1 (Figure 8C)	T2 (Figure 8D)	T3 (Figure 8E)	T4 (Figure 8F)
CC (Figure 7A)	-0.1360	0.1213	0.2420	0.0888	1.1892
PC		0.3306	0.5011	0.2342	1.6739
T1			0.1389	0.0039	1.3548
T2				-0.0924	1.3298
T3					0.9968

Table 10. Calculated T values from regression analysis of Mean Green Index at 25°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1+n2-4}$ or $t_0 < -t_{\alpha/2,\, n1+n2-4}$

PC vs T1, PC vs T2, and T1 vs T2; Total DF = 38, T = 2.0244

PC vs T3, PC vs T4, T1 vs T3, T1 vs T4, T2 vs T3, T2 vs T4; Total DF = 34, T = 2.0322

T3 vs T4; Total DF = 30, T = 2.0423

CC vs PC, CC vs T1, CC vs T2; Total DF = 28, T = 2.0484

CC vs T3, CC vs T4; Total DF = 24, T = 2.0639

No significant differences.

	PC (Figure 9B)	T1 (Figure 9C)	T2 (Figure 9D)	T3 (Figure 9E)	T4 (Figure 9F)
CC (Figure 9A)	*-4.4122	*-2.9428	*-4.3974	-0.8645	-0.7947
PC		*2.6180	1.0820	*2.5520	1.8277
T1			-1.8261	1.0104	0.5605
T2				*2.0753	1.3700
T3					-0.1492

Table 11. Calculated T values from regression analysis of Mean Blue Index at 25°C

H_0: $\beta_1 = \beta_2$; $\alpha = 0.05$; Reject H_0 if $t_0 > t_{\alpha/2,\, n1+n2-4}$ or $t_0 < -t_{\alpha/2,\, n1+n2-4}$

PC vs T1, PC vs T2, and T1 vs T2; Total DF = 38, T = 2.0244

PC vs T3, PC vs T4, T1 vs T3, T1 vs T4, T2 vs T3, T2 vs T4; Total DF = 34, T = 2.0322

T3 vs T4; Total DF = 30, T = 2.0423

CC vs PC, CC vs T1, CC vs T2; Total DF = 28, T = 2.0484

CC vs T3, CC vs T4; Total DF = 24, T = 2.0639

* Significant difference

CHAPTER 3. SUMMARY AND RECOMMENDATIONS

Summary

Canned peach halves were packaged into active EVOH pouches and analyzed for color and texture changes during a one-year shelf-life study. For color analysis, digital photography, Adobe Photoshop, and regression analysis were used. For texture analysis, a Wagner model FT 011 Fruit Tester was used. The main objective of this study was to assess the efficacy of the EVOH pouch in combination with a proprietary, tin-based oxidation inhibiting material with regard to the qualities of color and texture of the peach halves studied at 25°C, 35°C, and 45°C.

Unacceptable browning was used to determine the end of shelf-life condition for the pouches. The endpoint for the 45°C study was reached after 4.5 weeks, the endpoint for the 35°C study was reached after 21 weeks, and the endpoint for the 25°C study was reached after 48 weeks. With regard to color, all of the peaches in the EVOH pouches darkened over time. However, it was found that the oxidation inhibiting material did increase the shelf-life of the peach halves based on the maintenance of color in the T3 and T4 samples. For several weeks during the study, pouches with the T3 and T4 levels of oxidation inhibiting material did appear to have a much brighter color than samples with lower levels of this material.

Regression analysis of the RGB color components in photos of the peach halves revealed that in general, the red color component decreased and the blue color component increased over time in each temperature condition. This corresponded to the visual observation of overall darkening in the peaches. In the 25°C samples, there were significant differences in mean red and mean blue color in T3 samples. This finding, in combination with the visual observation of brighter color in the T3 and T4 pouches, indicated that the oxidation inhibiting material did help maintain the color of the peaches to some degree.

It was observed that the T4 samples at 25°C appeared brighter than the PC, T1, T2, and T3 samples for a twelve week period during the study. During this time it was also observed that the T3 pouches appeared brighter than the PC, T1, and T2 pouches. This occurred between weeks eighteen and thirty of the study. After this point, the T3 and T4 pouches darkened to almost the same level as the T2 pouches. In the 35°C samples, it was observed that the T3 and T4 samples looked much brighter than the PC, T1, and T2 samples until week seventeen of the study. At this point, there were several T3 samples which appeared to be approaching the endpoint condition. Other T3 samples, however, remained more brightly colored.

However, although the T3 and T4 levels of oxidation inhibitor were observed to have a preservation effect on the color of the peaches at both 25°C and 35°C, it may not be desirable to use this oxidation inhibiting material at these high levels. The T3 and T4 pouches were observed to have a metallic odor and it is therefore possible that the packaging system had a negative effect on the product. In addition, these samples did eventually darken to almost the same degree as the samples with lower levels of oxidation inhibitor.

With regard to texture, all of the samples softened over time. It was expected that the oxidation inhibiting material would help preserve the texture of the peach halves throughout the shelf-life of the product. The histograms in Figures 1 – 8 show how the texture of the peaches shifted over time at 25°C and 35°C. These graphs show that the peaches softened over time. Additionally, the graphs show a wide distribution in the data. This wide distribution could be due, in part, to the wide textural variability inherent in peaches.

Recommendations

The use of oxidation inhibitors in fruit packaging is a relatively new area of food packaging. Design of the active package for this application is a complicated task and requires further study to determine the ideal amount of oxidation inhibitor to use. The methods outlined in this study provide useful techniques to analyze color and texture during shelf-life storage in an active package. Future research areas could include repeating the methods used here with modifications made to reduce the variability in the color data. Reduction of this variability would be an important factor in future study.

The initial fill process could be conducted at a fruit packaging plant to ensure commercial sterility conditions and prevent the amount of random spoilage seen in this study. Headspace flushing could be used to ensure that maximum levels of oxygen are removed from the pouch prior to sealing. Beginning the fill with fresh fruit instead of canned would enable a more direct comparison with commercially canned product since the study samples would only be cooked once instead of twice.

It is also recommended that reduced temperatures be used for the accelerated aging conditions. Industry standards call for 25°C to approximate ambient conditions and 35°C for accelerated aging. Anything above this temperature is simply too hot for fruit that has been heat processed twice.

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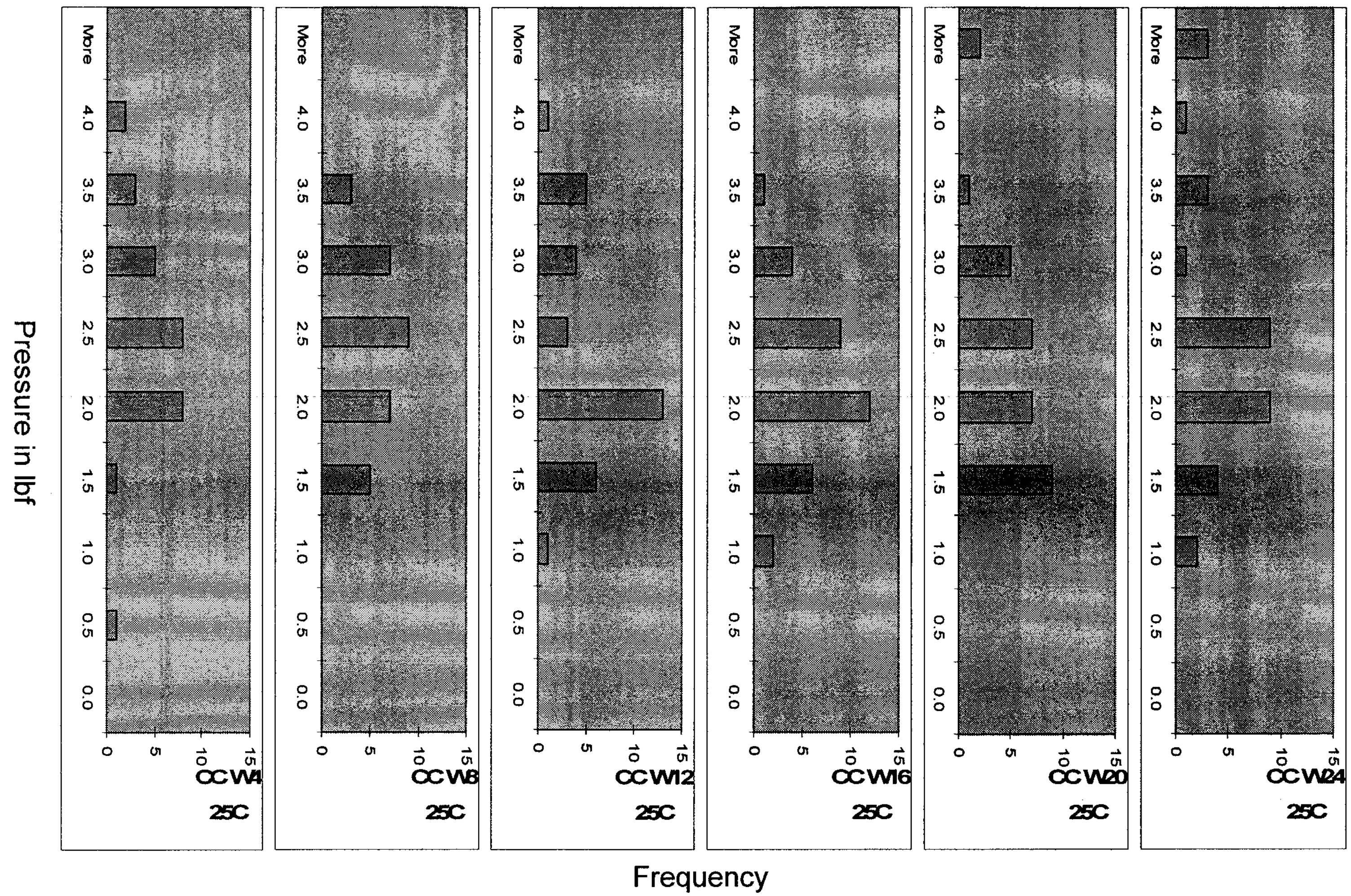

Figure 1A. Texture of Can Control at 25°C for weeks 4 - 24.

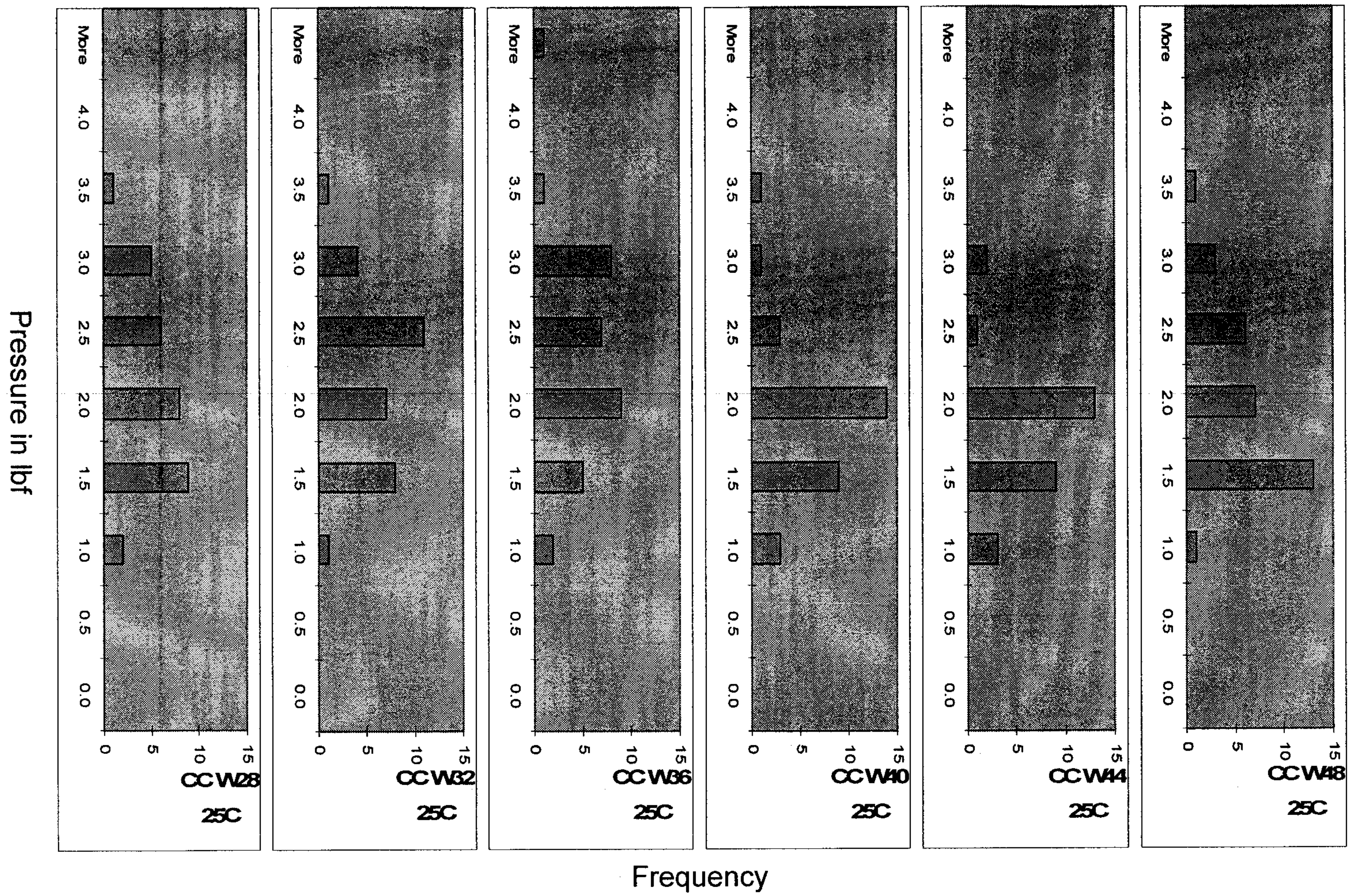

Figure 1B. Texture of Can Control at 25°C for weeks 28 - 48.

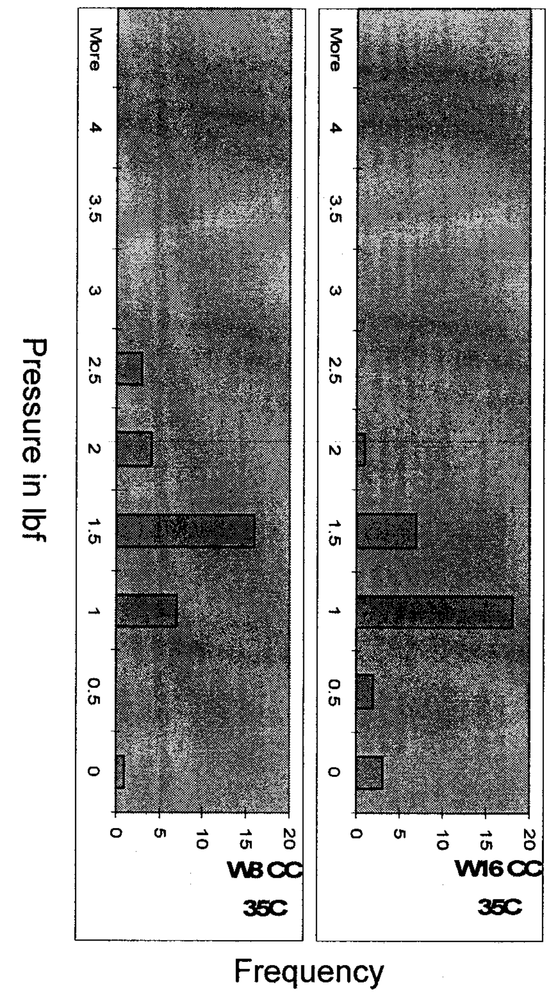

Figure 2. Texture of Can Control at 35°C for weeks 8 and 16.

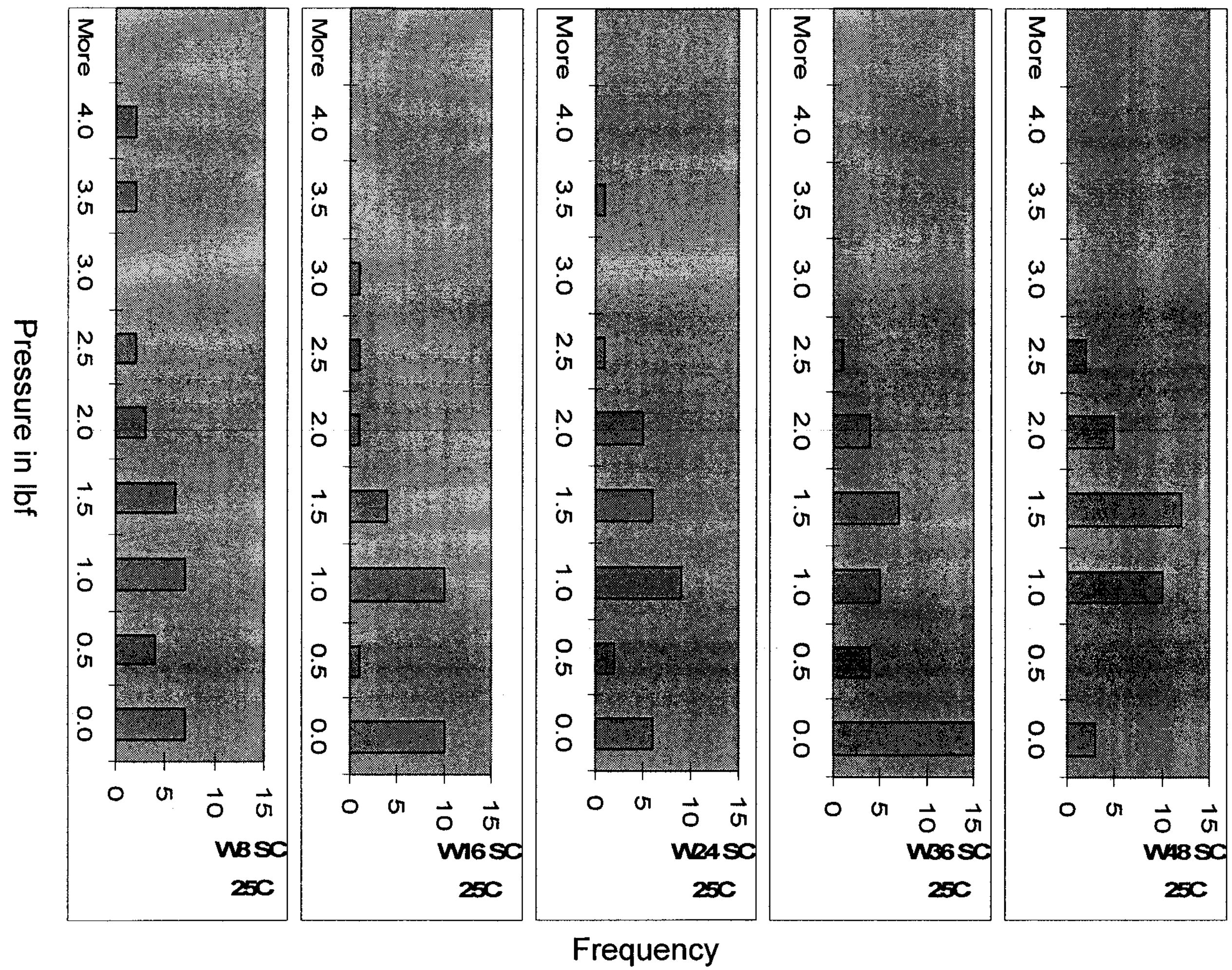

Figure 3. Texture of PC Pouches at 25°C for weeks 8 - 48.

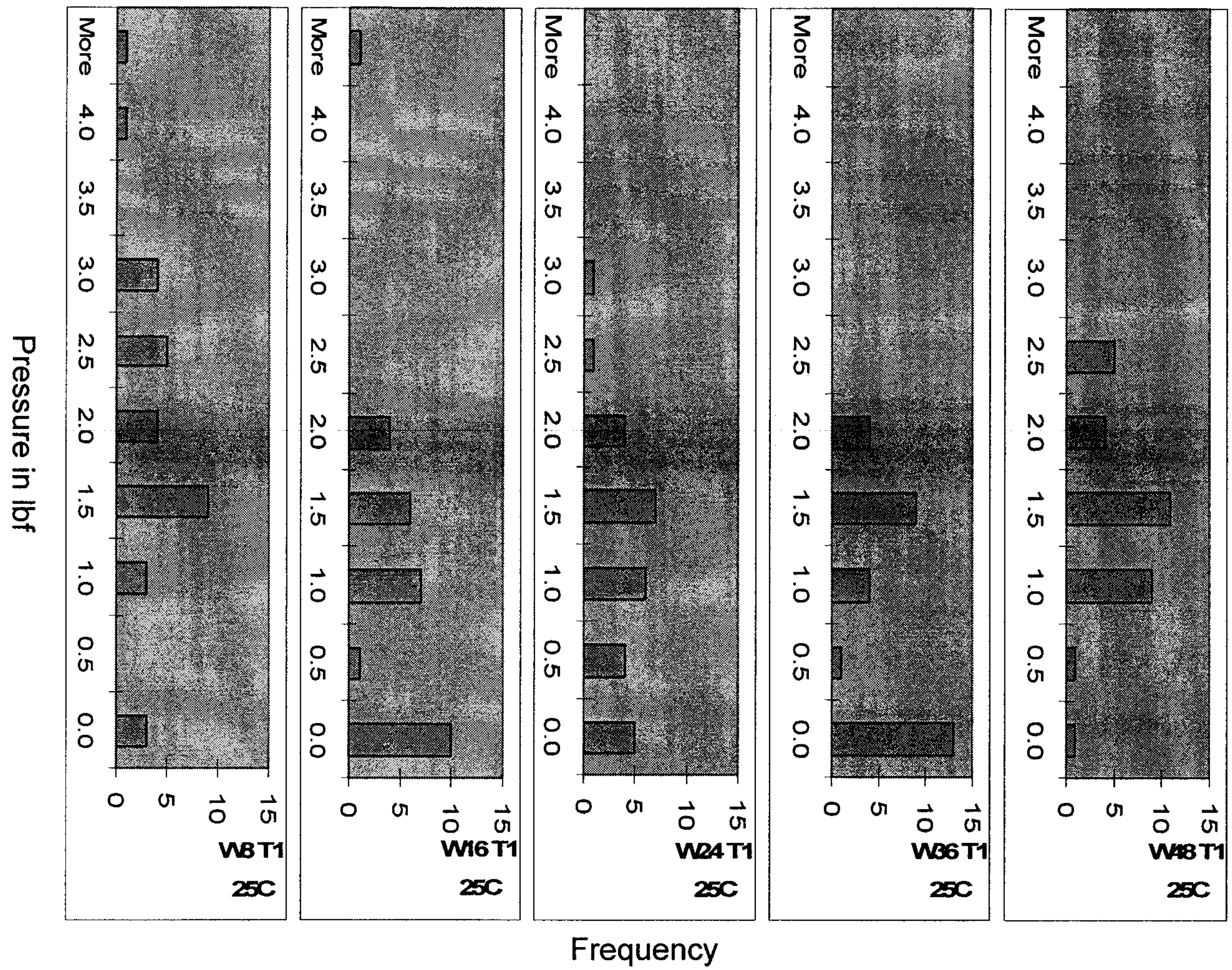

Figure 4. Texture of T1 Pouches at 25°C for weeks 8 - 48.

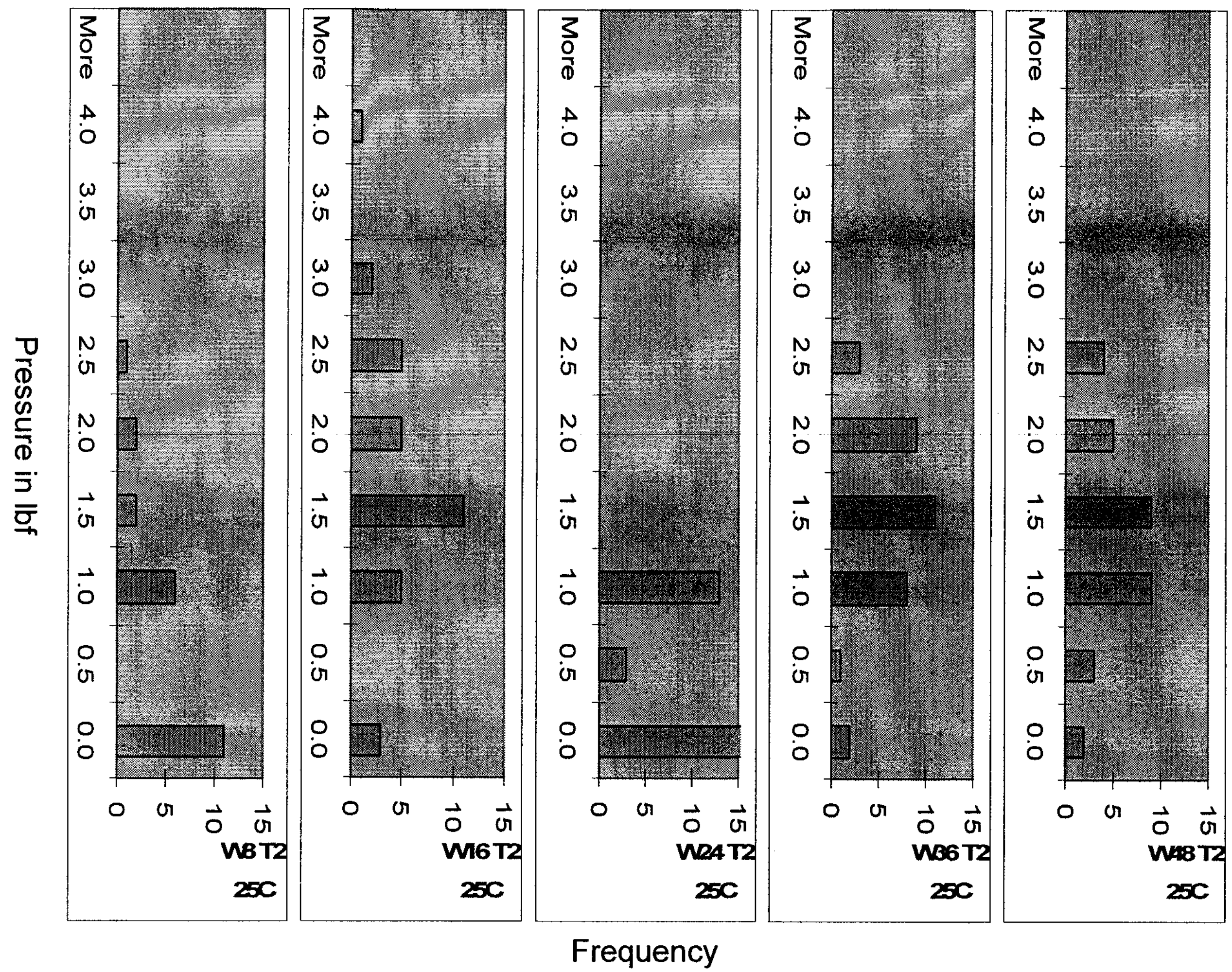

Figure 5. Texture of T2 Pouches at 25°C for weeks 8 - 48.

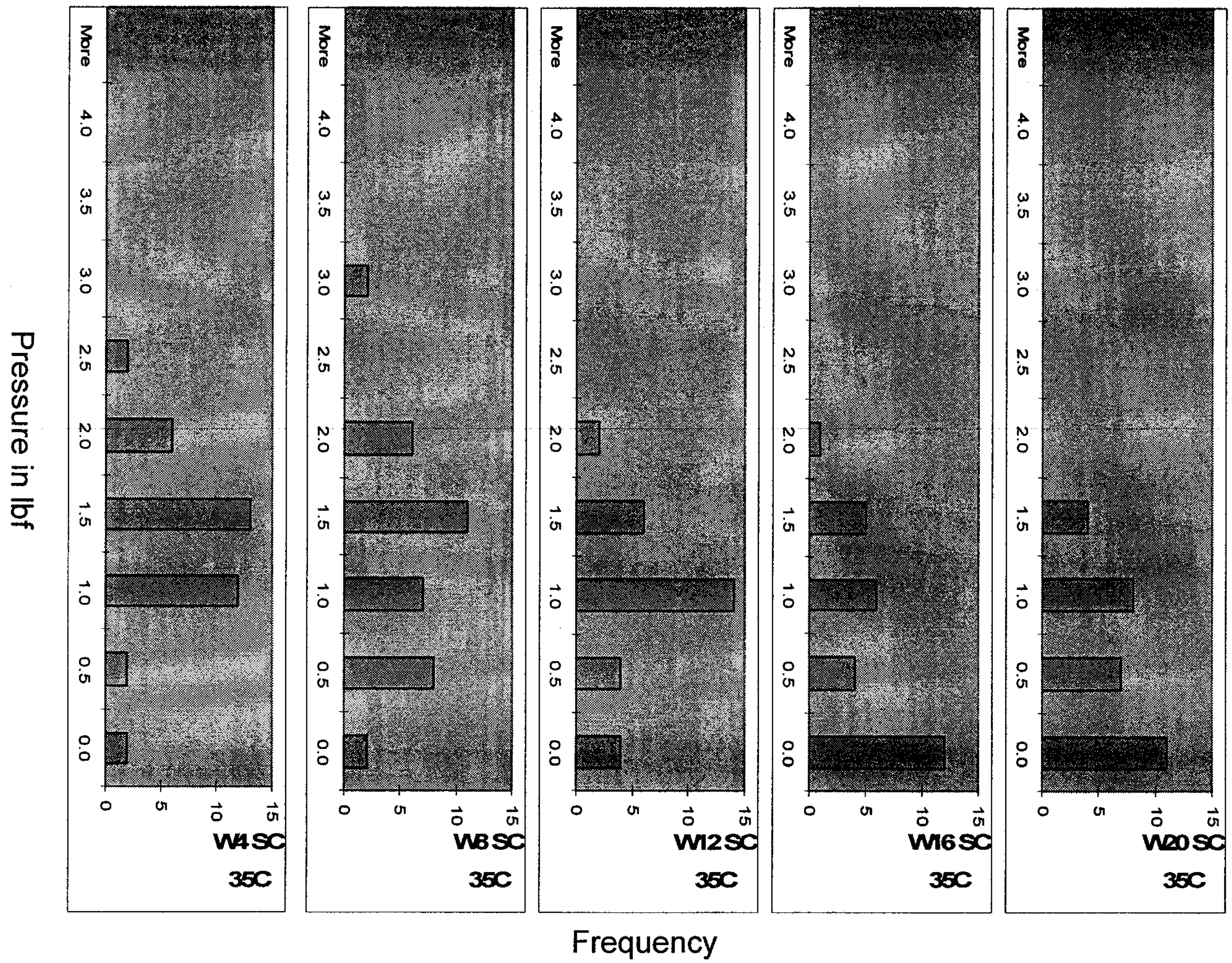

Figure 6. Texture of PC Pouches at 35°C for weeks 4 - 20.

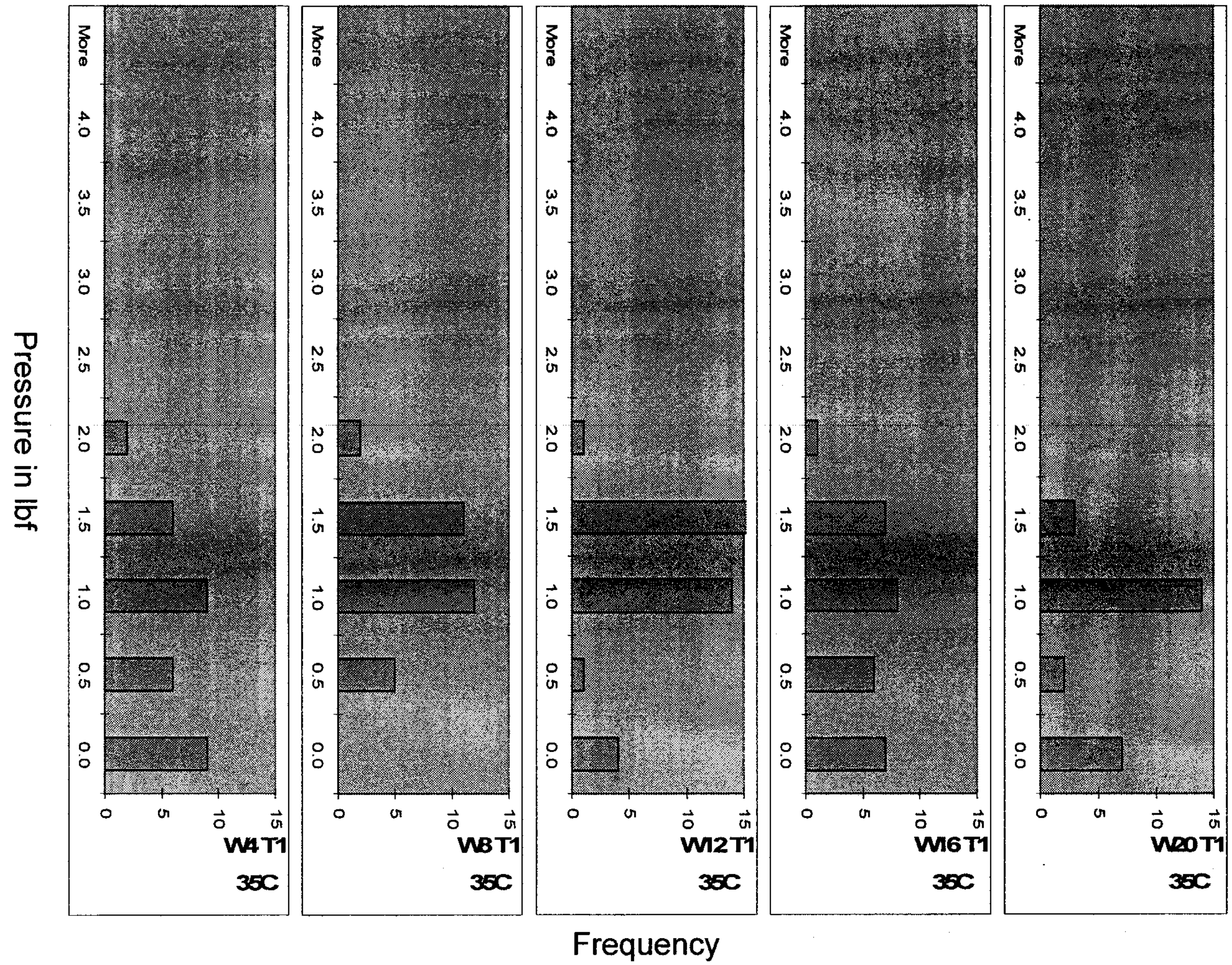

Figure 7. Texture of T1 Pouches at 35°C for weeks 4 - 20.

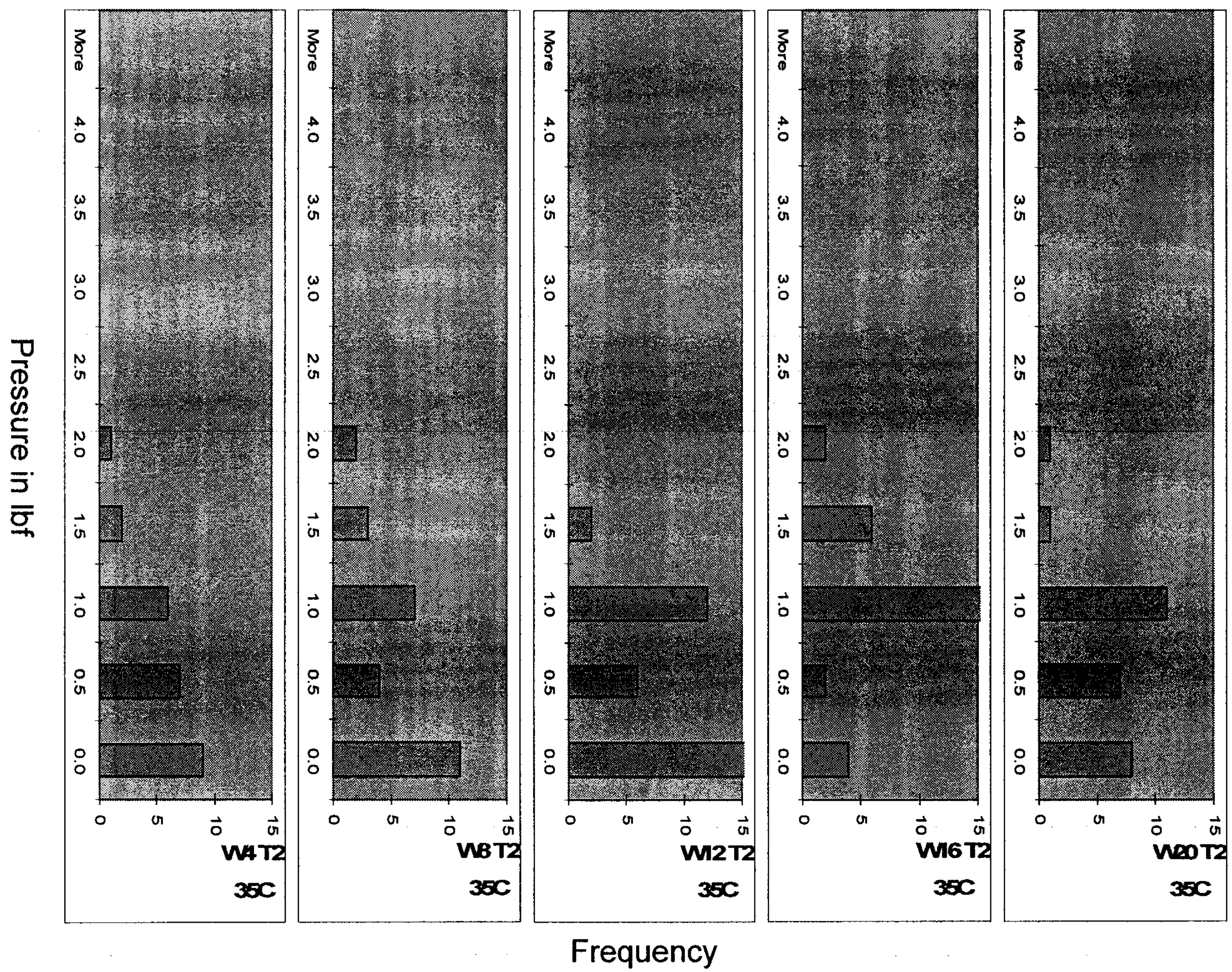

Figure 8. Texture of T2 Pouches at 35°C for weeks 4 - 20.

Appendix A. Summary of Experimental Design

Temperature Condition	**Pouch Control** No oxidation inhibitor	**Test 1** one 4"x4" square oxidation inhibitor	**Test 2** two 4"x4" squares oxidation inhibitor	**Test 3** four 4"x4" squares oxidation inhibitor	**Test 4** eight 4"x4" squares oxidation inhibitor	**Total**
25°C Can Control *Duration*: 24 mo (1st 12 mo only) *Frequency:* Color: 4 wk Texture: 4 wk	25 cans 3 spares					32 cans
35°C Can Control *Duration*: 4 mo *Frequency:* Color: 4 wks Texture: 4 wk	4 cans					4 cans
25°C pouches *Duration*: 24 mo (1st 12 mo only) *Frequency:* Color: 2 wk Texture: 8 wk	13 samples 2 spares	13 samples 1 spare	13 samples 1 spare	3 samples (weeks 80, 88, 96) 1 spare	3 samples (weeks 80, 88, 96) 1 spare	45 pouches
35°C pouches *Duration:* 12 mo *Frequency:* Color: 1 wk Texture: 4 wk	13 samples 2 spares	13 samples 1 spare	13 samples 1 spare	3 samples (weeks 40, 44, 48) 1 spare	3 samples (weeks 40, 44, 48) 1 spare	45 pouches
45°C pouches *Duration:* 6 mo *Frequency:* Color: 0.5 wk	13 samples 2 spares	13 samples 2 spare	13 samples 2 spare			45 pouches

Notes: Endpoint for 45°C study was reached after 4.5 weeks.

Endpoint for 35°C study was reached after 21 weeks

Endpoint for 25°C study was reached after 48 weeks.

The last two texture evaluations for 25°C study were done at months 9 and 12 instead of month 8 and 10 to satisfy the one-year commitment to Morningstar Fruit/Liberty Packing Company.

Appendix B.

Peach Sample Evaluation Schedule

PULL		DATE	SAMPLE	QUANTITY	TEMP CONDITION 25C	35C	45C
INITIAL FILL		08/19/04 - 08/23/04		30 cans/135 bags			
week 0		09/02/04	CA, CE25, TE251, TE252, CE35, TE351, TE352, CE45, TE451, TE452	1 can/9 bags	color	color	color
week 0.5		09/07/04	CE45, TE451, TE452	3 bags			color
week 1		09/09/04	CE45, TE451, TE452	3 bags			color
week 1.5		09/14/04	CE45, TE451, TE452	3 bags			color
week 2		09/16/04	CA, CE25, TE251, TE252, CE35, TE351, TE352, CE45, TE451, TE452	1 can/9 bags	color/texture	color	color
week 2.5		09/21/04	CE45, TE451, TE452	3 bags			color
week 3		09/23/04	CE45, TE451, TE452, CE35, TE351, TE352	6 bags		color	color
week 3.5		09/28/04	CE45, TE451, TE452	3 bags			color
week 4	month 1	09/30/04	CA, CE25, TE251, TE252, CE35, TE351, TE352, CE45, TE451, TE452	1 can/9 bags	color/texture	color/texture	color
week 4.5		10/05/04	CE45, TE451, TE452	3 bags			color
week 5		10/07/04	CE45, TE451, TE452, CE35, TE351, TE352	6 bags		color	color
week 5.5		10/12/04	CE45, TE451, TE452	3 bags			color
week 6		10/14/04	CA, CE25, TE251, TE252, CE35, TE351, TE352, CE45, TE451, TE452	1 can/9 bags	color/texture	color	color
week 6.5		10/19/04	CE45, TE451, TE452	3 bags			color
week 7		10/21/04	CE45, TE451, TE452, CE35, TE351, TE352	6 bags		color	color
week 7.5		10/26/04					
week 8	month 2	10/28/04	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color/texture	
week 8.5		11/02/04					
week 9		11/04/04	CE35, TE351, TE352	3 bags		color	
week 9.5		11/09/04					
week 10		11/11/04	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color	
week 10.5		11/16/04					
week 11		11/18/04	CE35, TE351, TE352	3 bags		color	
week 11.5		11/23/04					
week 12	month 3	11/25/04	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color/texture	
week 12.5		11/30/04					
week 13		12/02/04	CE35, TE351, TE352	3 bags		color	
week 13.5		12/07/04					

PULL		DATE	SAMPLE	QUANTITY	TEMP CONDITION		
					25C	35C	45C
week 14		12/09/04	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color	
week 14.5		12/14/04					
week 15		12/16/04	CE35, TE351, TE352	3 bags		color	
week 15.5		12/21/04					
week 16	month 4	12/23/04	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color/texture	
week 16.5		12/28/04					
week 17		12/30/04	CE35, TE351, TE352	3 bags		color	
week 17.5		01/04/05					
week 18		01/06/05	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color	
week 18.5		01/11/05					
week 19		01/13/05	CE35, TE351, TE352	3 bags		color	
week 19.5		01/18/05					
week 20	month 5	01/20/05	CA, CE25, TE251, TE252, CE35, TE351, TE352	1 can/6 bags	color/texture	color/texture	
week 20.5		01/25/05					
week 21		01/27/05	CE35, TE351, TE352	3 bags		color	
week 21.5		02/01/05					
week 22		02/03/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 22.5		02/08/05					
week 23		02/10/05					
week 23.5		02/15/05					
week 24	month 6	02/17/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 24.5		02/22/05					
week 25		02/24/05					
week 25.5		03/01/05					
week 26		03/03/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 26.5		03/08/05					
week 27		03/10/05					
week 27.5		03/15/05					
week 28	month 7	03/17/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 28.5		03/22/05					
week 29		03/24/05					

PULL		DATE	SAMPLE	QUANTITY	TEMP CONDITION 25C	35C	45C
week 29.5		03/29/05					
week 30		03/31/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 30.5		04/05/05					
week 31		04/07/05					
week 31.5		04/12/05					
week 32	month 8	04/14/05	CA, CA35, CE25, TE251, TE252	2 cans/3 bags	color/texture	color/texture	
week 32.5		04/19/05					
week 33		04/21/05					
week 33.5		04/26/05					
week 34		04/28/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 34.5		05/03/05					
week 35		05/05/05					
week 35.5		05/10/05					
week 36	month 9	05/12/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 36.5		05/17/05					
week 37		05/19/05					
week 37.5		05/24/05					
week 38		05/26/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 38.5		05/31/05					
week 39		06/02/05					
week 39.5		06/07/05					
week 40	month 10	06/09/05	CA, CA35, CE25, TE251, TE252	2 cans/3 bags	color/texture	color/texture	
week 40.5		06/14/05					
week 41		06/16/05					
week 41.5		06/21/05					
week 42		06/23/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 42.5		06/28/05					
week 43		06/30/05					
week 43.5		07/05/05					
week 44	month 11	07/07/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		

PULL		DATE	SAMPLE	QUANTITY	TEMP CONDITION		
					25C	35C	45C
week 44.5		07/12/05					
week 45		07/14/05					
week 45.5		07/19/05					
week 46		07/21/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		
week 46.5		07/26/05					
week 47		07/28/05					
week 47.5		08/02/05					
week 48	month 12	08/04/05	CA, CE25, TE251, TE252	1 can/3 bags	color/texture		

CAN controls: 25 + 5 spares = 30 total

EVOH control bags: 13 + 2 spares = 15 x 3 conditions = 45
EVOH test bags: 26 + 4 spares = 30 x 3 conditions = 90
Total EVOH bags: 135

45 degrees: color photos twice a week
35 degrees: color photos weekly, texture every 4 weeks or every 2 weeks if color change is noted
25 degrees: color photos biweekly, texture every 8 weeks or every 4 weeks if color change is noted

KEY:
CA = CAN CONTROL @ 25 (cans at room temperature)
CA35 = CAN CONTROL @ 35 (4 cans at 35C)
CE25, CE35, CE45 = CONTROL EVOH @ 25, 35, 45 without oxidation inhibitor
TE251, TE351, TE451 = TEST 1 EVOH @ 25, 35, 45 with 4x4 oxidation inhibitor
TE252, TE352, TE452 = TEST 2 EVOH @ 25, 35, 45 with 4x8 oxidation inhibitor

Appendix C.

Statistical Analysis for Comparing Two Slopes (Zar, 1996).

Test the hypothesis that the slopes are equal:

The parameter of interest is β, the slope of the regression line.

H_0: $\beta_1 = \beta_2$

H_1: $\beta_1 <> \beta_2$

Use significance level $\alpha = 0.05$ for this two-tailed test.

Test statistic: $t_0 = (b_1 - b_2) / S_{b1-b2}$

where $S_{b1-b2} = \sqrt{}\,(\,(Syx)_p^2 / (\sum x^2)_1 + (Syx)_p^2 / (\sum x^2)_2\,)$

and $(Syx)_p^2$ = (Residual SS)$_1$ + (Residual SS)$_2$ /(Residual DF)$_1$ + (Residual DF)$_2$

and (Residual SS) = $\sum y^2 - (\sum xy)^2 / \sum x^2$

and (Residual DF) = $n - 2$

and $\sum y^2 = \sum Y_i^2 - (\sum Y_i)^2 / n$

and $\sum x^2 = \sum X_i^2 - (\sum X_i)^2 / n$

and $\sum xy = \sum X_i Y_i - (\sum X_i \sum Y_i / n)$

Degrees of Freedom = $(n_1 - 2) + (n_2 - 2) = n_1 + n_2 - 4$

Rejection region: Reject H_0 if $t_0 > t_{\alpha/2,\, n1+n2-4}$ or $t_0 < -t_{\alpha/2,\, n1+n2-4}$

EXAMPLE:

For Mean Blue Index at 45°C, compare the Pouch Control to T1.

$n_1 = n_2 = 7$ $\quad\quad t_{\alpha/2,\, n1+n2-4} = t_{0.05/2,\,10} = t_{0.025,\,10} = 2.228$
$(n_1 - 2) = (n_2 - 2) = (7 - 2) = 5$
$(n_1 - 2) + (n_2 - 2) = (5 + 5) = 10$

	Blue PC					**Blue T1**			
x1	**y1**	**x1^2**	**x1*y1**	**y1^2**	**x2**	**y2**	**x2^2**	**x2*y2**	**y2^2**
1	2.05	1.00	2.05	4.20	1	2.43	1.00	2.43	5.90
2	8.18	4.00	16.36	66.91	2	9.39	4.00	18.78	88.17
2.5	10.79	6.25	26.98	116.42	2.5	13.04	6.25	32.60	170.04
3	12.96	9.00	38.88	167.96	3	15.63	9.00	46.89	244.30
3.5	14.71	12.25	51.49	216.38	3.5	15.12	12.25	52.92	228.61
4	14.64	16.00	58.56	214.33	4	14.29	16.00	57.16	204.20
4.5	16.19	20.25	72.86	262.12	4.5	15.73	20.25	70.79	247.43

For Pouch Control PC:

$\sum x^2 = \sum X_1^2 - (\sum X_1)^2 / n$

$= 68.75 - (20.5)^2 / 7$

$= 68.75 - (420.25) / 7$

$= 8.71$

$\sum xy = \sum X_1Y_1 - (\sum X_1 \sum Y_1 / n)$

$= 267.17 - (20.5 * 79.52 / 7)$

$= 267.17 - 232.88$

$= 34.29$

$\sum y^2 = \sum Y_1^2 - (\sum Y_1)^2 / n$

$= 1048.33 - (79.52)^2 / 7$

$= 1048.33 - 903.35$

$= 144.98$

For Test-1 T1:

$\sum x^2 = \sum X_2^2 - (\sum X_2)^2 / n$

$= 68.75 - (20.5)^2 / 7$

$= 68.75 - (420.25) / 7$

$= 8.71$

$\sum xy = \sum X_2Y_2 - (\sum X_2 \sum Y_2 / n)$

$= 281.57 - (20.5 * 85.63 / 7)$

$= 281.57 - 250.77$

$= 30.79$

$\sum y^2 = \sum Y_2^2 - (\sum Y_2)^2 / n$

$= 1188.66 - (85.63)^2 / 7$

$= 1188.66 - 1047.49$

$= 141.17$

$\beta = \sum xy / \sum x^2$

$\beta = 34.29 / 8.71 = 3.93$

Residual SS = $RSS_1 = \sum y^2 - (\sum xy)^2 / \sum x^2$

$= 144.98 - (34.29)^2 / 8.71$

$= 10.09$

$\beta = \sum xy / \sum x^2$

$\beta = 30.79 / 8.71 = 3.53$

$RSS_2 = \sum y^2 - (\sum xy)^2 / \sum x^2$

$= 141.17 - (30.79)^2 / 8.71$

$= 32.36$

Residual DF = RDF = $n_1 - 2 = 7 - 2 = 5$

$(Syx)_p^2 = (RSS_1 + RSS_2) / (RDF_1 + RDF_2)$

$= (10.09 + 32.36) / (5 + 5)$

$= 42.45 / 10 = 4.245$

$S_{b1-b2} = \sqrt{((Syx)_p^2 / (\sum x^2)_1 + (Syx)_p^2 / (\sum x^2)_2)}$

$= \sqrt{(4.245 / 8.71) + (4.245 / 8.71)}$

$= 0.987$

$t_0 = (b_1 - b_2) / S_{b1-b2}$

$= (3.93 - 3.53) / 0.987 = 0.405$

Reject H_0 if $t_0 > t_{\alpha/2, n1+n2-4} = t_{0.025, 10} = 2.228$

Since 0.405 is not > 2.228 we cannot reject H_0 and conclude that there is not a significant difference between the two slopes.

Appendix D. Raw Data and Regression Analysis for Mean Red, Green and Blue Index at 45°C for PC, T1 and T2.

Red PC

x1	y1	x1^2	x1*y1	y1^2
1	166.27	1	166.27	27645.71
2	174.51	4	349.02	30453.74
2.5	162.62	6.25	406.55	26445.26
3	149.64	9	448.92	22392.13
3.5	161.38	12.25	564.83	26043.50
4	163.87	16	655.48	26853.38
4.5	153.37	20.25	690.17	23522.36

Red T1

x2	y2	x2^2	x2*y2	y2^2
1	171.14	1	171.14	29288.90
2	170.84	4	341.68	29186.31
2.5	168.39	6.25	420.975	28355.19
3	148.60	9	445.8	22081.96
3.5	150.34	12.25	526.19	22602.12
4	156.89	16	627.56	24614.47
4.5	142.94	20.25	643.23	20431.84

Red T2

x3	y3	x3^2	x3*y3	y3^2
1	178.00	1	178.00	31684.00
2	178.88	4	357.76	31998.05
2.5	165.14	6.25	412.85	27271.22
3	148.24	9	444.72	21975.10
3.5	163.31	12.25	571.59	26670.16
4	161.05	16	644.20	25937.10
4.5	147.86	20.25	665.37	21862.58

PC vs T1		**PC vs T2**		**T1 vs T2**	
n1	7	n1	7	n1	7
n2	7	n2	7	n2	7
slope	-3.7768	slope	-8.2188	slope	-8.1876
SS	281.1603	SS	230.5059	SS	348.2358
PMS	51.1666	PMS	62.9396	PMS	57.8742
SE	3.4268	SE	3.8007	SE	3.6445
Tvalue	1.2962	Tvalue	1.1605	Tvalue	-0.0085
TotalDF	10	TotalDF	10	TotalDF	10
T	2.2281	T	2.2281	T	2.2281

Green PC

x1	y1	x1^2	x1*y1	y1^2
1	65.23	1	65.23	4254.95
2	71.86	4	143.72	5163.86
2.5	64.11	6.25	160.28	4110.09
3	62.52	9	187.56	3908.75
3.5	66.73	12.25	233.56	4452.89
4	71.65	16	286.60	5133.72
4.5	65.63	20.25	295.34	4307.30

Green T1

x2	y2	x2^2	x2*y2	y2^2
1	67.73	1	67.73	4587.35
2	71.39	4	142.78	5096.53
2.5	68.74	6.25	171.85	4725.19
3	63.57	9	190.71	4041.14
3.5	61.74	12.25	216.09	3811.83
4	66.12	16	264.48	4371.85
4.5	60.69	20.25	273.11	3683.28

Green T2

x3	y3	x3^2	x3*y3	y3^2
1	75.42	1	75.42	5688.18
2	74.48	4	148.96	5547.27
2.5	66.17	6.25	165.43	4378.47
3	61.63	9	184.89	3798.26
3.5	70.84	12.25	247.94	5018.31
4	70.01	16	280.04	4901.40
4.5	64.47	20.25	290.12	4156.38

PC vs T1		**PC vs T2**		**T1 vs T2**	
n1	7	n1	7	n1	7
n2	7	n2	7	n2	7
slope	0.2862	slope	-2.3340	slope	-2.4980
SS	77.8029	SS	43.7605	SS	104.1205
PMS	12.1563	PMS	18.1923	PMS	14.7881
SE	1.6703	SE	2.0423	SE	1.8423
Tvalue	1.5687	Tvalue	1.3626	Tvalue	0.0890
TotalDF	10	TotalDF	10	TotalDF	10
T	2.2281	T	2.2281	T	2.2281

Blue PC

x1	y1	x1^2	x1*y1	y1^2
1	2.05	1.00	2.05	4.20
2	8.18	4.00	16.36	66.91
2.5	10.79	6.25	26.98	116.42
3	12.96	9.00	38.88	167.96
3.5	14.71	12.25	51.49	216.38
4	14.64	16.00	58.56	214.33
4.5	16.19	20.25	72.86	262.12

Blue T1

x2	y2	x2^2	x2*y2	y2^2
1	2.43	1.00	2.43	5.90
2	9.39	4.00	18.78	88.17
2.5	13.04	6.25	32.60	170.04
3	15.63	9.00	46.89	244.30
3.5	15.12	12.25	52.92	228.61
4	14.29	16.00	57.16	204.20
4.5	15.73	20.25	70.79	247.43

Blue T2

x3	y3	x3^2	x3*y3	y3^2
1	3.24	1.00	3.24	10.50
2	9.38	4.00	18.76	87.98
2.5	12.49	6.25	31.23	156.00
3	12.48	9.00	37.44	155.75
3.5	17.18	12.25	60.13	295.15
4	15.11	16.00	60.44	228.31
4.5	17.58	20.25	79.11	309.06

PC vs T1		**PC vs T2**		**T1 vs T2**	
n1	7	n1	7	n1	7
n2	7	n2	7	n2	7
slope	3.9343	slope	3.5334	slope	3.9260
SS	10.0942	SS	32.3676	SS	15.6869
PMS	4.2462	PMS	2.5781	PMS	4.8054
SE	0.9872	SE	0.7692	SE	1.0502
Tvalue	0.4061	Tvalue	0.0109	Tvalue	-0.3738
TotalDF	10	TotalDF	10	TotalDF	10
T	2.2281	T	2.2281	T	2.2281

Appendix E. Raw Data and Regression Analysis for Mean Red, Green and Blue Index at 35°C for PC, T1, T2, T3 and T4.

Red PC

x1	y1	x1^2	x1*y1	y1^2
7	206.78	49	1447.46	42757.97
8	207.59	64	1660.72	43093.61
9	195.35	81	1758.15	38161.62
10	199.35	100	1993.50	39740.42
11	196.36	121	2159.96	38557.25
12	195.76	144	2349.12	38321.98
13	196.01	169	2548.13	38419.92
14	203.25	196	2845.50	41310.56
15	201.77	225	3026.58	40711.81
16	200.49	256	3207.81	40195.57
17	194.81	289	3311.80	37951.72
18	191.53	324	3447.61	36685.27
19	191.99	361	3647.77	36859.39
20	194.77	400	3895.48	37936.91
21	195.73	441	4110.38	38311.21

Red T1

x2	y2	x2^2	x2*y2	y2^2
7	196.77	49	1377.39	38718.43
8	197.37	64	1578.96	38954.92
9	208.62	81	1877.58	43522.30
10	199.93	100	1999.30	39972.00
11	199.55	121	2195.05	39820.20
12	209.50	144	2514.00	43890.25
13	199.96	169	2599.48	39984.00
14	203.52	196	2849.28	41420.39
15	201.03	225	3015.45	40413.06
16	198.91	256	3182.56	39565.19
17	197.57	289	3358.69	39033.90
18	197.19	324	3549.42	38883.90
19	191.08	361	3630.52	36511.57
20	199.14	400	3982.80	39656.74
21	199.92	441	4198.32	39968.01

Red T2

x3	y3	x3^2	x3*y3	y3^2
7	200.76	49	1405.32	40304.58
8	215.26	64	1722.08	46336.87
9	208.59	81	1877.31	43509.79
10	207.40	100	2074.00	43014.76
11	198.60	121	2184.60	39441.96
12	205.93	144	2471.16	42407.16
13	200.03	169	2600.39	40012.00
14	203.30	196	2846.20	41330.89
15	201.34	225	3020.16	40539.41
16	197.58	256	3161.25	39037.07
17	194.93	289	3313.77	37996.73
18	194.20	324	3495.51	37711.70
19	191.94	361	3646.81	36840.00
20	194.91	400	3898.15	37988.93
21	198.05	441	4159.10	39224.79

Red T3

x4	y4	x4^2	x4*y4	y4^2
15	201.27	225	3019.05	40509.61
16	196.59	256	3145.44	38647.63
17	192.55	289	3273.27	37073.58
18	195.04	324	3510.63	38038.65
19	189.39	361	3598.41	35868.57
20	197.41	400	3948.10	38968.73
21	198.34	441	4165.14	39338.76

Red T4

x5	y5	x5^2	x5*y5	y5^2
15	198.49	225	2977.40	39399.60
16	192.63	256	3082.13	37107.60
17	186.03	289	3162.45	34605.92
18	193.50	324	3483.00	37442.25
19	189.08	361	3592.52	35751.25
20	194.41	400	3888.27	37796.54
21	196.51	441	4126.64	38614.87

PC vs T1	
n1	15
n2	15
slope	-0.6847
SS	209.7690
PMS	18.0915
SE	0.3595
Tvalue	-0.9904
TotalDF	26
T	2.0555

PC vs T2	
n1	15
n2	15
slope	-0.3287
SS	260.6109
PMS	16.9834
SE	0.3483
Tvalue	1.1467
TotalDF	26
T	2.0555

PC vs T3	
n1	15
n2	7
slope	-0.6847
SS	209.7690
PMS	16.5450
SE	0.8062
Tvalue	-0.3924
TotalDF	18
T	2.1009

PC vs T4	
n1	15
n2	7
slope	-0.3684
SS	88.0409
PMS	17.6992
SE	0.8339
Tvalue	-0.8492
TotalDF	18
T	2.1009

T1 vs T2	
n1	15
n2	15
slope	-1.0841
SS	231.7999
PMS	18.9389
SE	0.3678
Tvalue	2.0539
TotalDF	26
T	2.0555

T1 vs T3	
n1	15
n2	7
slope	-0.3287
SS	260.6109
PMS	19.3695
SE	0.8723
Tvalue	0.0455
TotalDF	18
T	2.1009

T1 vs T4	
n1	15
n2	7
slope	-0.3684
SS	88.0409
PMS	20.5238
SE	0.8979
Tvalue	-0.3921
TotalDF	18
T	2.1009

T2 vs T3	
n1	15
n2	7
slope	-1.0841
SS	231.7999
PMS	17.7689
SE	0.8355
Tvalue	-0.8567
TotalDF	18
T	2.1009

T2 vs T4	
n1	15
n2	7
slope	-0.3684
SS	88.0409
PMS	18.9231
SE	0.8622
Tvalue	-1.2844
TotalDF	18
T	2.1009

T3 vs T4	
n1	7
n2	7
slope	0.0233
SS	108.8167
PMS	19.6858
SE	1.1858
Tvalue	-0.3303
TotalDF	10
T	2.2281

Green PC

x1	y1	x1^2	x1*y1	y1^2
7	100.10	49	700.70	10020.01
8	104.01	64	832.08	10818.08
9	105.18	81	946.62	11062.83
10	106.75	100	1067.50	11395.56
11	103.16	121	1134.76	10641.99
12	105.75	144	1269.00	11183.06
13	96.95	169	1260.35	9399.30
14	105.41	196	1475.74	11111.27
15	102.51	225	1537.65	10508.30
16	105.47	256	1687.52	11123.92
17	101.85	289	1731.45	10373.42
18	102.61	324	1846.98	10528.81
19	105.01	361	1995.19	11027.10
20	104.82	400	2096.40	10987.23
21	109.74	441	2304.54	12042.87

Green T1

x2	y2	x2^2	x2*y2	y2^2
7	97.28	49	680.96	9463.40
8	97.46	64	779.68	9498.45
9	106.11	81	954.99	11259.33
10	97.01	100	970.10	9410.94
11	95.14	121	1046.54	9051.62
12	101.93	144	1223.16	10389.72
13	103.93	169	1351.09	10801.44
14	102.24	196	1431.36	10453.02
15	102.70	225	1540.45	10546.61
16	103.26	256	1652.21	10663.32
17	101.07	289	1718.11	10214.13
18	105.93	324	1906.74	11221.16
19	99.78	361	1895.73	9955.05
20	106.84	400	2136.70	11413.72
21	109.32	441	2295.72	11950.86

Green T2

x3	y3	x3^2	x3*y3	y3^2
7	96.76	49	677.32	9362.50
8	111.10	64	888.80	12343.21
9	101.21	81	910.89	10243.46
10	103.51	100	1035.10	10714.32
11	95.40	121	1049.40	9101.16
12	96.47	144	1157.64	9306.46
13	102.32	169	1330.16	10469.38
14	102.51	196	1435.14	10508.30
15	101.12	225	1516.74	10224.45
16	101.52	256	1624.29	10305.90
17	98.95	289	1682.19	9791.60
18	104.90	324	1888.16	11003.49
19	99.99	361	1899.81	9998.00
20	105.22	400	2104.45	11071.77
21	107.97	441	2267.37	11657.52

Green T3

x4	y4	x4^2	x4*y4	y4^2
15	104.55	225	1568.25	10930.70
16	98.55	256	1576.72	9711.12
17	102.10	289	1735.62	10423.39
18	103.67	324	1866.06	10747.47
19	103.93	361	1974.67	10801.44
20	107.85	400	2157.00	11631.62
21	108.03	441	2268.63	11670.48

Green T4

x5	y5	x5^2	x5*y5	y5^2
15	104.27	225	1564.05	10872.23
16	102.52	256	1640.37	10511.03
17	102.82	289	1747.94	10571.95
18	110.19	324	1983.42	12141.84
19	107.38	361	2040.28	11531.18
20	109.99	400	2199.73	12097.07
21	111.63	441	2344.16	12460.51

PC vs T1		PC vs T2		PC vs T3		PC vs T4	
n1	15	n1	15	n1	15	n1	15
n2	15	n2	15	n2	7	n2	7
slope	0.2	slope	0.5848	slope	0.2000	slope	1.1030
SS	113.9686	SS	140.0832	SS	113.9686	SS	30.7344
PMS	9.7712	PMS	13.7120	PMS	8.0391	PMS	7.6606
SE	0.2642	SE	0.3130	SE	0.5620	SE	0.5486
Tvalue	-1.4565	Tvalue	-0.0708	Tvalue	-1.6069	Tvalue	-2.3411
TotalDF	26	TotalDF	26	TotalDF	18	TotalDF	18
T	2.0555	T	2.0555	T	2.1009	T	2.1009

T1 vs T2		T1 vs T3		T1 vs T4	
n1	15	n1	15	n1	15
n2	15	n2	7	n2	7
slope	0.2222	slope	0.5848	slope	1.1030
SS	242.5440	SS	140.0832	SS	30.7344
PMS	14.7164	PMS	9.4899	PMS	9.1114
SE	0.3242	SE	0.6106	SE	0.5983
Tvalue	1.1185	Tvalue	-0.8488	Tvalue	-1.5034
TotalDF	26	TotalDF	18	TotalDF	18
T	2.0555	T	2.1009	T	2.1009

T2 vs T3		T2 vs T4		T3 vs T4	
n1	15	n1	15	n1	7
n2	7	n2	7	n2	7
slope	0.2222	slope	1.1030	slope	1.4843
SS	242.5440	SS	30.7344	SS	23.9225
PMS	15.1821	PMS	14.8037	PMS	5.4657
SE	0.7723	SE	0.7626	SE	0.6248
Tvalue	-1.1406	Tvalue	-1.6550	Tvalue	-0.6102
TotalDF	18	TotalDF	18	TotalDF	10
T	2.1009	T	2.1009	T	2.2281

Blue
PC

x1	y1	x1^2	x1*y1	y1^2
7	17.87	49	125.09	319.34
8	18.83	64	150.64	354.57
9	32.73	81	294.57	1071.25
10	35.56	100	355.60	1264.51
11	32.72	121	359.92	1070.60
12	42.47	144	509.64	1803.70
13	23.54	169	306.02	554.13
14	28.98	196	405.72	839.84
15	26.03	225	390.43	677.47
16	27.97	256	447.55	782.41
17	30.91	289	525.40	955.18
18	36.24	324	652.39	1313.63
19	36.05	361	684.91	1299.46
20	38.56	400	771.24	1487.03
21	41.63	441	874.23	1733.06

Blue
T1

x2	y2	x2^2	x2*y2	y2^2
7	21.54	49	150.78	463.97
8	21.88	64	175.04	478.73
9	26.41	81	237.69	697.49
10	22.22	100	222.20	493.73
11	16.39	121	180.29	268.63
12	19.57	144	234.84	382.98
13	31.58	169	410.54	997.30
14	25.82	196	361.48	666.67
15	26.86	225	402.95	721.64
16	30.73	256	491.73	944.54
17	27.34	289	464.70	747.20
18	33.00	324	594.00	1089.00
19	31.19	361	592.52	972.50
20	32.60	400	652.00	1062.76
21	37.21	441	781.41	1384.58

Blue
T2

y2^2	x3	y3	x3^2	x3*y3	y3^2
463.97	7	20.41	49	142.87	416.57
478.73	8	29.64	64	237.12	878.53
697.49	9	17.43	81	156.87	303.80
493.73	10	22.56	100	225.60	508.95
268.63	11	21.61	121	237.71	466.99
382.98	12	18.78	144	225.36	352.69
997.30	13	35.41	169	460.33	1253.87
666.67	14	28.24	196	395.36	797.50
721.64	15	25.71	225	385.71	661.21
944.54	16	30.24	256	483.78	914.22
747.20	17	29.41	289	499.89	864.65
1089.00	18	37.43	324	673.70	1400.82
972.50	19	33.00	361	627.00	1089.00
1062.76	20	38.03	400	760.65	1446.47
1384.58	21	37.93	441	796.58	1438.87

Blue
T3

x4	y4	x4^2	x4*y4	y4^2
15	33.54	225	503.10	1124.93
16	29.27	256	468.32	856.73
17	37.04	289	629.68	1371.96
18	33.37	324	600.66	1113.56
19	42.58	361	808.93	1812.63
20	41.47	400	829.30	1719.35
21	39.55	441	830.45	1563.81

Blue
T4

x5	y5	x5^2	x5*y5	y5^2
15	33.97	225	509.60	1154.19
16	40.05	256	640.85	1604.27
17	44.14	289	750.44	1948.63
18	46.39	324	835.02	2152.03
19	46.40	361	881.54	2152.65
20	46.91	400	938.13	2200.24
21	48.36	441	1015.49	2338.37

PC vs T1		PC vs T2		PC vs T3		PC vs T4	
n1	15	n1	15	n1	15	n1	15
n2	15	n2	15	n2	7	n2	7
slope	0.9717	slope	1.0409	slope	0.9717	slope	1.7121
SS	529.4772	SS	169.1577	SS	529.4772	SS	59.6285
PMS	26.8706	PMS	30.9674	PMS	32.7281	PMS	31.0697
SE	0.4381	SE	0.4703	SE	1.1339	SE	1.1048
Tvalue	-0.1578	Tvalue	-0.5684	Tvalue	-0.6530	Tvalue	-1.0312
TotalDF	26	TotalDF	26	TotalDF	18	TotalDF	18
T	2.0555	T	2.0555	T	2.1009	T	2.1009

T1 vs T2		T1 vs T3		T1 vs T4	
n1	15	n1	15	n1	15
n2	15	n2	7	n2	7
slope	1.2390	slope	1.0409	slope	1.7121
SS	275.6740	SS	169.1577	SS	59.6285
PMS	17.1089	PMS	12.7103	PMS	11.0520
SE	0.3496	SE	0.7066	SE	0.6589
Tvalue	-0.5668	Tvalue	-0.9499	Tvalue	-1.6241
TotalDF	26	TotalDF	18	TotalDF	18
T	2.0555	T	2.1009	T	2.1009

T2 vs T3		T2 vs T4		T3 vs T4	
n1	15	n1	15	n1	7
n2	7	n2	7	n2	7
slope	1.2390	slope	1.7121	slope	2.1111
SS	275.6740	SS	59.6285	SS	29.7781
PMS	18.6279	PMS	16.9696	PMS	8.9407
SE	0.8555	SE	0.8165	SE	0.7991
Tvalue	-0.5530	Tvalue	-1.0680	Tvalue	-0.4992
TotalDF	18	TotalDF	18	TotalDF	10
T	2.1009	T	2.1009	T	2.2281

Appendix F. Raw Data and Regression Analysis for Mean Red, Green and Blue Index at 25°C for PC, T1 T2, T3 and T4.

Red PC					Red T1				
x1	**y1**	**x1^2**	**x1*y1**	**y1^2**	**x2**	**y2**	**x2^2**	**x2*y2**	**y2^2**
8	205.94	64	1647.52	42411.28	8	207.70	64	1661.60	43139.29
10	199.98	100	1999.80	39992.00	10	204.75	100	2047.50	41922.56
12	211.60	144	2539.20	44774.56	12	206.84	144	2482.08	42782.79
14	210.44	196	2946.16	44284.99	14	199.67	196	2795.38	39868.11
16	203.98	256	3263.62	41606.21	16	201.20	256	3219.15	40480.10
18	201.37	324	3624.66	40549.88	18	197.02	324	3546.36	38816.88
20	202.23	400	4044.55	40895.96	20	202.35	400	4047.00	40945.52
22	204.27	484	4493.87	41724.87	22	203.53	484	4477.62	41423.78
24	198.87	576	4772.88	39549.28	24	197.48	576	4739.48	38997.69
26	203.77	676	5298.02	41522.21	26	200.27	676	5206.97	40107.27
28	202.68	784	5675.04	41079.18	28	201.30	784	5636.46	40522.50
30	203.46	900	6103.65	41393.94	30	204.32	900	6129.54	41745.85
32	202.20	1024	6470.24	40882.82	32	202.24	1024	6471.55	40899.40
34	201.03	1156	6835.02	40413.06	34	203.00	1156	6901.86	41207.38
36	202.42	1296	7287.12	40973.86	36	201.93	1296	7269.62	40777.34
38	202.91	1444	7710.58	41172.47	38	206.01	1444	7828.19	42438.06
40	196.21	1600	7848.40	38498.36	40	200.62	1600	8024.80	40248.38
42	202.31	1764	8497.02	40929.34	42	203.22	1764	8535.03	41296.34
44	201.33	1936	8858.52	40533.77	44	201.50	1936	8866.00	40602.25
46	203.40	2116	9356.40	41371.56	46	199.91	2116	9195.86	39964.01
48	200.00	2304	9600.00	40000.00	48	199.30	2304	9566.52	39721.49

Red T2

x3	y3	x3^2	x3*y3	y3^2
8	209.00	64	1672.00	43681.00
10	210.86	100	2108.60	44461.94
12	208.73	144	2504.76	43568.21
14	203.20	196	2844.80	41290.24
16	201.95	256	3231.12	40781.78
18	198.82	324	3578.76	39529.39
20	201.93	400	4038.50	40773.71
22	203.62	484	4479.54	41459.29
24	197.94	576	4750.56	39180.24
26	203.57	676	5292.82	41440.74
28	201.74	784	5648.64	40697.87
30	204.26	900	6127.71	41720.98
32	202.85	1024	6491.20	41148.12
34	202.83	1156	6896.22	41140.01
36	202.35	1296	7284.65	40946.10
38	203.54	1444	7734.37	41426.90
40	199.40	1600	7975.92	39759.56
42	203.27	1764	8537.26	41317.88
44	200.65	1936	8828.51	40259.62
46	199.18	2116	9162.10	39671.08
48	198.53	2304	9529.20	39412.18

Red T3

x4	y4	x4^2	x4*y2	y4^2
16	201.19	256	3219.04	40477.42
18	198.37	324	3570.66	39350.66
20	196.91	400	3938.20	38773.55
22	200.26	484	4405.72	40104.07
24	197.59	576	4742.16	39041.81
26	204.01	676	5304.26	41620.08
28	203.46	784	5696.88	41395.97
30	206.13	900	6183.90	42489.58
32	204.29	1024	6537.28	41734.40
34	203.24	1156	6910.16	41306.50
36	196.42	1296	7071.12	38580.82
38	206.23	1444	7836.74	42530.81
40	199.90	1600	7996.00	39960.01
42	207.81	1764	8728.02	43185.00
44	203.72	1936	8963.68	41501.84
46	198.78	2116	9143.88	39513.49
48	201.90	2304	9691.20	40763.61

Red T4

x5	y5	x5^2	x5*y5	y5^2
16	200.07	256	3201.04	40026.00
18	189.92	324	3418.47	36067.71
20	196.85	400	3936.90	38747.95
22	193.64	484	4260.08	37496.45
24	192.57	576	4621.68	37083.20
26	200.98	676	5225.48	40392.96
28	197.42	784	5527.76	38974.66
30	200.78	900	6023.40	40312.61
32	199.32	1024	6378.24	39728.46
34	198.83	1156	6760.22	39533.37
36	203.70	1296	7333.20	41493.69
38	212.59	1444	8078.42	45194.51
40	189.69	1600	7587.60	35982.30
42	198.12	1764	8321.04	39251.53
44	199.46	1936	8776.24	39784.29
46	196.28	2116	9028.88	38525.84
48	194.84	2304	9352.32	37962.63

PC vs T1		PC vs T2		PC vs T3		PC vs T4	
n1	21	n1	21	n1	21	n1	21
n2	21	n2	21	n2	17	n2	17
slope	-0.1358	slope	-0.0608	slope	-0.1358	slope	0.1055
SS	177.0909	SS	146.8709	SS	177.0909	SS	173.7489
PMS	8.5253	PMS	8.5469	PMS	10.3188	PMS	18.5787
SE	0.0744	SE	0.0745	SE	0.0984	SE	0.1320
Tvalue	-1.0082	Tvalue	0.4074	Tvalue	-2.4539	Tvalue	-1.7236
Total DF	38	TotalDF	38	TotalDF	34	TotalDF	34
T	2.0244	T	2.0244	T	2.0322	T	2.0322

T1 vs T2		T1 vs T3		T1 vs T4	
n1	21	n1	21	n1	21
n2	21	n2	17	n2	17
slope	-0.1662	slope	-0.0608	slope	0.1055
SS	147.6906	SS	146.8709	SS	173.7489
PMS	7.7516	PMS	9.4300	PMS	17.6899
SE	0.0709	SE	0.0940	SE	0.1288
Tvalue	1.4851	Tvalue	-1.7691	Tvalue	-1.1838
TotalDF	38	TotalDF	34	TotalDF	34
T	2.0244	T	2.0322	T	2.0322

T2 vs T3		T2 vs T4		T3 vs T4	
n1	21	n1	21	n1	17
n2	17	n2	17	n2	17
slope	-0.1662	slope	0.1055	slope	0.0916
SS	147.6906	SS	173.7489	SS	454.5865
PMS	9.4541	PMS	17.7140	PMS	20.9445
SE	0.0941	SE	0.1289	SE	0.1602
Tvalue	-2.8860	Tvalue	-2.007	Tvalue	0.0866
TotalDF	34	TotalDF	34	TotalDF	30
T	2.0322	T	2.0322	T	2.0423

	Green PC					Green T1			
x1	**y1**	**x1^2**	**x1*y1**	**y1^2**	**x2**	**y2**	**x2^2**	**x2*y2**	**y2^2**
8	100.52	64	804.16	10104.27	8	106.80	64	854.40	11406.24
10	99.61	100	996.10	9922.15	10	102.87	100	1028.70	10582.24
12	101.73	144	1220.76	10348.99	12	101.96	144	1223.52	10395.84
14	103.45	196	1448.30	10701.90	14	98.83	196	1383.62	9767.37
16	99.87	256	1597.92	9974.02	16	100.77	256	1612.29	10154.26
18	104.03	324	1872.54	10822.24	18	103.49	324	1862.82	10710.18
20	104.00	400	2080.00	10816.00	20	105.53	400	2110.67	11137.28
22	104.34	484	2295.55	10887.53	22	104.78	484	2305.16	10978.85
24	98.85	576	2372.40	9771.32	24	101.27	576	2430.44	10255.28
26	103.46	676	2689.83	10702.94	26	100.56	676	2614.56	10112.31
28	104.50	784	2925.86	10919.21	28	108.33	784	3033.18	11734.96
30	103.43	900	3102.75	10696.73	30	104.94	900	3148.20	11012.40
32	104.53	1024	3344.80	10925.48	32	105.92	1024	3389.44	11219.05
34	101.68	1156	3456.95	10337.81	34	104.15	1156	3541.03	10846.81
36	102.19	1296	3678.66	10441.77	36	103.19	1296	3714.84	10648.18
38	99.82	1444	3793.16	9964.03	38	104.57	1444	3973.76	10935.41
40	98.39	1600	3935.60	9680.59	40	101.92	1600	4076.90	10388.20
42	104.11	1764	4372.62	10838.89	42	103.34	1764	4340.18	10678.64
44	103.78	1936	4566.32	10770.29	44	104.69	1936	4606.25	10959.47
46	103.60	2116	4765.60	10732.96	46	102.10	2116	4696.60	10424.41
48	104.48	2304	5015.04	10916.07	48	104.12	2304	4997.64	10840.45

Green T2

x3	y3	x3^2	x3*y3	y3^2
8	107.58	64	860.64	11573.46
10	106.28	100	1062.80	11295.44
12	101.31	144	1215.72	10263.72
14	99.98	196	1399.72	9996.00
16	103.28	256	1652.54	10667.58
18	103.88	324	1869.82	10790.82
20	104.78	400	2095.63	10979.20
22	104.17	484	2291.72	10851.16
24	100.79	576	2418.96	10158.62
26	102.34	676	2660.73	10472.60
28	105.11	784	2943.16	11048.71
30	104.30	900	3129.09	10879.09
32	105.59	1024	3378.93	11149.55
34	104.13	1156	3540.57	10843.95
36	103.69	1296	3732.89	10751.91
38	102.11	1444	3880.33	10427.27
40	102.48	1600	4099.20	10502.15
42	105.13	1764	4415.63	11053.16
44	106.55	1936	4688.29	11353.33
46	102.88	2116	4732.57	10584.71
48	105.75	2304	5076.12	11183.59

Green T3

x4	y4	x4^2	x4*y4	y4^2
16	105.05	256	1680.80	11035.50
18	102.77	324	1849.86	10561.67
20	103.63	400	2072.60	10739.18
22	108.87	484	2395.14	11852.68
24	99.91	576	2397.84	9982.01
26	101.61	676	2641.86	10324.59
28	106.15	784	2972.20	11267.82
30	103.13	900	3093.90	10635.80
32	106.30	1024	3401.60	11299.69
34	103.35	1156	3513.90	10681.22
36	98.46	1296	3544.56	9694.37
38	101.30	1444	3849.40	10261.69
40	104.64	1600	4185.60	10949.53
42	107.87	1764	4530.54	11635.94
44	108.89	1936	4791.16	11857.03
46	100.61	2116	4628.06	10122.37
48	105.51	2304	5064.48	11132.36

Green T4

x5	y5	x5^2	x5*y5	y5^2
16	111.29	256	1780.56	12384.35
18	109.81	324	1976.58	12058.24
20	106.99	400	2139.80	11446.86
22	109.85	484	2416.70	12067.02
24	100.17	576	2404.08	10034.03
26	107.02	676	2782.52	11453.28
28	106.87	784	2992.36	11421.20
30	106.11	900	3183.30	11259.33
32	106.63	1024	3412.16	11369.96
34	107.27	1156	3647.18	11506.85
36	104.54	1296	3763.44	10928.61
38	106.86	1444	4060.68	11419.06
40	102.14	1600	4085.60	10432.58
42	105.56	1764	4433.52	11142.91
44	109.34	1936	4810.96	11955.24
46	105.07	2116	4833.22	11039.70
48	107.61	2304	5165.28	11579.91

PC vs T1		PC vs T2		PC vs T3		PC vs T4	
n1	21	n1	21	n1	21	n1	21
n2	21	n2	21	n2	17	n2	17
slope	0.0407	slope	0.0223	slope	0.0407	slope	0.0220
SS	80.7399	SS	99.9459	SS	80.7399	SS	150.2638
PMS	4.7549	PMS	4.1454	PMS	6.7942	PMS	5.6297
SE	0.0556	SE	0.0519	SE	0.0798	SE	0.0726
Tvalue	0.3306	Tvalue	0.5011	Tvalue	0.2342	Tvalue	1.6739
TotalDF	38	TotalDF	38	TotalDF	34	TotalDF	34
T	2.0244	T	2.0244	T	2.0322	T	2.0322

T1 vs T2		T1 vs T3		T1 vs T4	
n1	21	n1	21	n1	21
n2	21	n2	17	n2	17
slope	0.0147	slope	0.0223	slope	0.0220
SS	76.7859	SS	99.9459	SS	150.2638
PMS	4.6508	PMS	7.3591	PMS	6.1945
SE	0.0550	SE	0.0831	SE	0.0762
Tvalue	0.1389	Tvalue	0.0039	Tvalue	1.3548
TotalDF	38	TotalDF	34	TotalDF	34
T	2.0244	T	2.0322	T	2.0322

T2 vs T3		T2 vs T4		T3 vs T4	
n1	21	n1	21	n1	17.00
n2	17	n2	17	n2	15
slope	0.0147	slope	0.0220	slope	-0.0809
SS	76.7859	SS	150.2638	SS	110.6685
PMS	6.6779	PMS	5.5134	PMS	8.6977
SE	0.0791	SE	0.0719	SE	0.1032
Tvalue	-0.0924	Tvalue	1.3298	Tvalue	0.9968
TotalDF	34	TotalDF	34	TotalDF	30
T	2.0322	T	2.0322	T	2.0423

	Blue PC					Blue T1			
x1	**y1**	**x1^2**	**x1*y1**	**y1^2**	**x2**	**y2**	**x2^2**	**x2*y2**	**y2^2**
8	15.74	64	125.92	247.75	8	21.99	64	175.92	483.56
10	15.15	100	151.50	229.52	10	17.60	100	176.00	309.76
12	11.00	144	132.00	121.00	12	18.52	144	222.24	342.99
14	19.88	196	278.32	395.21	14	20.02	196	280.28	400.80
16	19.38	256	310.02	375.43	16	21.06	256	336.93	443.45
18	24.95	324	449.06	622.38	18	27.22	324	490.02	741.11
20	25.88	400	517.50	669.52	20	24.20	400	483.90	585.40
22	25.99	484	571.85	675.65	22	23.45	484	515.83	549.75
24	21.13	576	507.12	446.48	24	23.22	576	557.16	538.94
26	24.44	676	635.44	597.31	26	22.68	676	589.63	514.29
28	23.96	784	670.74	573.84	28	22.50	784	630.06	506.34
30	24.74	900	742.20	612.07	30	26.15	900	784.38	683.61
32	27.48	1024	879.36	755.15	32	26.13	1024	836.22	682.88
34	27.02	1156	918.51	729.81	34	25.71	1156	874.28	661.21
36	25.46	1296	916.56	648.21	36	25.70	1296	925.34	660.70
38	24.76	1444	940.88	613.06	38	23.48	1444	892.24	551.31
40	26.19	1600	1047.60	685.92	40	24.14	1600	965.40	582.50
42	26.81	1764	1126.02	718.78	42	23.98	1764	1006.95	574.80
44	28.28	1936	1244.32	799.76	44	27.35	1936	1203.29	747.89
46	29.30	2116	1347.80	858.49	46	28.49	2116	1310.43	811.54
48	29.74	2304	1427.52	884.47	48	25.88	2304	1242.12	669.65

Blue T2

x3	y3	x3^2	x3*y3	y3^2
8	15.49	64	123.92	239.94
10	22.09	100	220.90	487.97
12	19.25	144	231.00	370.56
14	20.81	196	291.34	433.06
16	23.46	256	375.28	550.14
18	25.58	324	460.42	654.28
20	25.92	400	518.30	671.59
22	23.13	484	508.88	535.05
24	23.25	576	557.89	540.36
26	21.99	676	571.70	483.50
28	23.19	784	649.36	537.84
30	23.95	900	718.41	573.47
32	24.98	1024	799.36	624.00
34	26.41	1156	897.89	697.41
36	25.54	1296	919.39	652.22
38	24.08	1444	914.96	579.75
40	28.27	1600	1130.80	799.19
42	27.10	1764	1138.20	734.41
44	31.58	1936	1389.61	997.42
46	30.86	2116	1419.56	952.34
48	30.20	2304	1449.60	912.04

Blue T3

x4	y4	x4^2	x4*y4	y4^2
16	24.51	256	392.16	600.74
18	20.98	324	377.64	440.16
20	26.91	400	538.20	724.15
22	28.00	484	616.00	784.00
24	20.74	576	497.76	430.15
26	18.03	676	468.78	325.08
28	22.85	784	639.80	522.12
30	18.53	900	555.90	343.36
32	23.22	1024	743.04	539.17
34	24.04	1156	817.36	577.92
36	23.11	1296	831.96	534.07
38	16.26	1444	617.88	264.39
40	28.72	1600	1148.80	824.84
42	22.87	1764	960.54	523.04
44	27.72	1936	1219.68	768.40
46	26.63	2116	1224.98	709.16
48	25.98	2304	1247.04	674.96

Blue T4

x5	y5	x5^2	x5*y5	y5^2
16	28.27	256	452.32	799.19
18	33.17	324	597.06	1100.25
20	23.99	400	479.80	575.52
22	32.72	484	719.73	1070.27
24	20.84	576	500.16	434.31
26	26.32	676	684.32	692.74
28	24.09	784	674.52	580.33
30	22.75	900	682.50	517.56
32	24.46	1024	782.72	598.29
34	28.96	1156	984.64	838.68
36	22.14	1296	797.04	490.18
38	16.39	1444	622.82	268.63
40	32.05	1600	1282.00	1027.20
42	26.31	1764	1105.02	692.22
44	32.38	1936	1424.72	1048.46
46	33.50	2116	1541.00	1122.25
48	33.85	2304	1624.80	1145.82

PC vs T1		PC vs T2		PC vs T3		PC vs T4	
n1	21	n1	21	n1	21	n1	21
n2	21	n2	21	n2	17	n2	17
slope	0.3302	slope	0.1669	slope	0.3302	slope	0.0774
SS	149.3247	SS	78.2171	SS	149.3247	SS	206.4644
PMS	5.9879	PMS	6.0678	PMS	10.4644	PMS	16.7329
SE	0.0624	SE	0.0628	SE	0.0990	SE	0. 1252
Tvalue	2.6180	Tvalue	1.0820	Tvalue	2.5520	Tvalue	1.8277
TotalDF	38	TotalDF	38	TotalDF	34	TotalDF	34
T	2.0244	T	2.0244	T	2.0322	T	2.0322

T1 vs T2		T1 vs T3		T1 vs T4	
n1	21	n1	21	n1	21
n2	21	n2	17	n2	17
slope	0.2622	slope	0.1669	slope	0.0774
SS	81.2530	SS	78.2171	SS	206.4644
PMS	4.1966	PMS	8.3730	PMS	14.6415
SE	0.0522	SE	0.0886	SE	0.1172
Tvalue	-1.8261	Tvalue	1.0104	Tvalue	0.5605
TotalDF	38	TotalDF	34	TotalDF	34
T	2.0244	T	2.0322	T	2.0322

T2 vs T3		T2 vs T4		T3 vs T4	
n1	21	n1	21	n1	17.00
n2	17	n2	17	n2	15
slope	0.2622	slope	0.0774	slope	0.1013
SS	81.2530	SS	206.4644	SS	419.5928
PMS	8.4623	PMS	14.7308	PMS	20.8686
SE	0.0891	SE	0.1175	SE	0.1599
Tvalue	2.0753	Tvalue	1.3700	Tvalue	-0.1492
TotalDF	34	TotalDF	34	TotalDF	30
T	2.0322	T	2.0322	T	2.0423